LIBRARY

OHIO NORTHERN UNIVERSITY

REGULATIONS

1. Not more than two books can be taken out at any one time and cannot be retained longer than two weeks.
2. At the expiration of two weeks books may be re-let if returned to the librarian in good condition.
3. A rental of two cents a day will be charged on each book held over two weeks.

Class No. 621.354 Accession No. 1114

Digitized by the Internet Archive
in 2025

https://archive.org/details/bwb_C0-AWZ-903

ELEMENTS
OF
STORAGE BATTERIES

UNIVERSITY OF WISCONSIN EXTENSION TEXTS

A series of Industrial and Engineering Education Textbooks, developed under the direction of Dean LOUIS E. REBER, University of Wisconsin Extension Division

Norris and Smith's
SHOP ARITHMETIC

Norris and Craigo's
ADVANCED SHOP MATHEMATICS

Hills'
MACHINE DRAWING

George's
ADVANCED SHOP DRAWING

Wooley and Meredith's
SHOP SKETCHING

Longfield's
SHEET METAL DRAFTING

Hobbs, Elliott, and Consoliver's
GASOLINE AUTOMOBILE

Norris, Winning, and Weaver's
GAS ENGINE IGNITION

Consoliver and Mitchell's
AUTOMOTIVE IGNITION SYSTEMS

Shealy's
HEAT

Shealy's
STEAM BOILERS

Shealy's
STEAM ENGINES

Jansky's
ELECTRICAL METERS

Jansky's
THEORY AND OPERATION OF D.-C. MACHINERY

Jansky's
ELEMENTARY MAGNETISM AND ELECTRICITY

Jansky's
PRINCIPLES OF RADIOTELEGRAPHY

Jansky and Faber's
PRINCIPLES OF THE TELEPHONE
Part I.—Subscribers' Apparatus

Hool's
ELEMENTS OF STRUCTURES

Hool's
REINFORCED CONCRETE CONSTRUCTION
Vol I.—Fundamental Principles
Vol. II.—Retaining Walls and Buildings
Vol. III.—Bridges and Culverts

Blair's
SHOW-CARD WRITING

Pulver's
MATERIALS OF CONSTRUCTION

Wines'
STRENGTH OF MATERIALS

Jansky's
ELEMENTS OF STORAGE BATTERIES

INDUSTRIAL EDUCATION SERIES

ELEMENTS
OF
STORAGE BATTERIES

PREPARED IN THE
EXTENSION DIVISION OF
THE UNIVERSITY OF WISCONSIN

BY
CYRIL M. JANSKY, B. S., B. A.
Professor of Electrical Engineering The University of Wisconsin

AND

HARRY P. WOOD, B. S., E. E.
Professor of Electrical Engineering The University of Wisconsin

First Edition
Second Impression

McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1923

COPYRIGHT, 1923, BY THE
McGRAW-HILL BOOK COMPANY, INC.

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

681.2124
J35c

PREFACE

The extended and varied uses of storage batteries, together with the radical changes in storage battery practice, have created a demand for a simple and direct exposition of the principles, operation and maintenance of these energy converters. This text is an attempt to meet that demand. The treatment is elementary. In addition to the specific discussion of storage batteries, the electrical and chemical principles which are necessary for an understanding of the operation of storage batteries are covered fully.

In preparing the text the authors have had in mind the needs of the non-technical man who uses or operates storage batteries and wishes to know something of the care, maintenance and repair of such batteries to insure the most efficient service.

The applications of storage batteries are so varied that it has been impossible to give the best practice in all cases. The authors, nevertheless, have attempted to give the general principles of good practice, and are under obligation to H. M. Beck, engineer of the Electric Storage Battery Company, for assistance in this particular. Mr. Beck read the manuscript and made many valuable suggestions. The authors are under obligation also to manufacturers of storage batteries and equipment used with batteries for the loan of cuts which illustrate their products. These companies are: General Electric Company, Westinghouse Electric and Manufacturing Company, Edison Storage Battery Company, Gould Storage Battery Company, Willard Storage Battery Company, Electric Storage Battery Company, Universal Battery Company, Cutler-Hammer Manufacturing Company, and the Kohler Company.

A word of appreciation should be extended also to Miss Cecelia McGuan, proofreader of the Extension Division, for valuable assistance in preparing the manuscript.

C. M. J.
H. P. W.

MADISON, WISCONSIN,
September, 1923.

CONTENTS

PAGE

PREFACE v

CHAPTER I. THE STORAGE CELL

ARTICLE

1. Primary and Secondary Cells 1
2. The Storage Cell 3
3. The Planté Type of Plate 3
4. The Faure or Pasted Type of Plate 4
5. The Positive Plate 4
6. The Negative Plate 5
7. The Positive Group 6
8. The Negative Group 6
9. Separators 6
10. The Electrolyte 7
11. Specific Gravity 8
12. Hydrometer or Acidimeter 10
13. Effect of Temperature on the Specific Gravity 12
14. General Assembly of the Lead Cell 13

CHAPTER II. FUNDAMENTAL ELECTRICAL QUANTITIES AND METERS

15. General 19
16. Electromotive Force or Electrical Pressure 19
17. Sources of Electromotive Force 20
18. Electric Current 21
19. Measurement of Electric Current 22
20. Ampere-hour Meter 24
21. Voltmeter 26
22. Resistance 26
23. Ohm's Law 28
24. Voltage Drop 29
25. Change of Resistance with Temperature 29
26. Power 30
27. Work and Energy 31

CHAPTER III. CHEMISTRY OF THE STORAGE CELL

28. Physical and Chemical Changes 35
29. Chemical Changes 35
30. Chemical Reactions 36
31. Chemical Symbols and Equations 37
32. Atoms and Molecules 39
33. Cell Reactions 40

ARTICLE PAGE
34. Variation in Specific Gravity during Charge and Discharge . . . 43
35. Faraday's Law . . . 43
36. Electrolysis . . . 44
37. The Ampere . . . 45
38. The Coulomb and Ampere-hour . . . 46
39. Equivalent Weights . . . 46
40. Applications of Faraday's Laws . . . 47
41. Voltage of a Lead Storage Cell . . . 49

CHAPTER IV. NICKEL-IRON-ALKALINE CELL

42. General . . . 53
43. Elements of the Edison Storage Cell . . . 53
44. The Container . . . 53
45. The Positive Plate of the Edison Cell . . . 54
46. The Negative Plate of the Edison Cell . . . 55
47. The Plate Groups . . . 56
48. The Electrolyte . . . 56
49. Voltage of the Edison Cell . . . 59
50. The Chemical Reactions of the Edison Cell . . . 59
51. Classes or Types of Edison Cells . . . 61
52. Permanence of the Edison Alkaline Storage Battery . . . 63

CHAPTER V. GENERAL CHARACTERISTICS OF STORAGE CELLS

53. General . . . 67
54. Charge and Discharge Rate . . . 67
55. Internal Resistance . . . 69
56. Effect of Internal Resistance on Output of Cell . . . 72
57. Freezing of Electrolyte . . . 73
58. Capacity of Storage Cells . . . 74
59. Efficiency of Storage Cells . . . 77
60. Specific Output . . . 81
61. Factors Affecting the Voltage of a Cell . . . 82

CHAPTER VI. CHARGING AND CARE OF STORAGE BATTERIES

62. General . . . 93
63. Cell Connections and Polarity of Circuits . . . 93
64. Simple Methods of Determining Polarity . . . 95
65. Nomenclature of Charging . . . 97
66. Charging Storage Batteries . . . 98
67. Methods of Charging . . . 99
68. Charging the Nickel-iron-alkaline Cell . . . 109

CHAPTER VII. CHARGING CIRCUITS AND EQUIPMENT

69. Control Resistances . . . 115
70. Counter-electromotive Force Cells . . . 121
71. End Cells . . . 122

ARTICLE PAGE
72. Motor-generator Charging Sets 124
73. Charging Equipment for Large Garages 127
74. Rectifiers for Charging Storage Batteries 129
75. Charging Value of Rectified Current 144

CHAPTER VIII. TESTING

76. General 148
77. Test for Ampere-hour Capacity 148
78. Test for Ampere-hour Efficiency 149
79. Test for Watt-hour Capacity and Efficiency 150
80. Temperature and Specific Gravity Tests 153
81. Voltage Tests 155
82. Test for Condition of Plates 157

CHAPTER IX. MAINTENANCE OF STORAGE BATTERIES

83. General 171
84. Replenishing the Electrolyte 171
85. Cleaning 173
86. Cleaning Nickel-iron Cell 175
87. Receiving a New Battery 176
88. Battery Room 178
89. Installation of Battery 179
90. Assembly of Cells 181
91. Dismantling Lead-acid Cells 185
92. Assembly of Vehicle Batteries 190
93. Lead Burning 192
94. Storage of Lead Cells 198
95. Storing the Nickel-iron Batteries 199

CHAPTER X. DISEASES OF BATTERIES

96. General 203
97. Local Action 203
98. Regeneration of Sulphated Plates 207
99. Shedding of Active Material 208
100. Loss of Capacity 209
101. Short-circuits 211
102. Deformation of Plates 212
103. Diagnosis of Storage Battery Troubles 216

CHAPTER XI. COMMERCIAL BATTERIES AND THEIR USES

104. Names and Distinguishing Characteristics 221
105. Planté and Faure Plates 221
106. Structural Characteristics 222
107. Use-controlling Characteristics 224
108. Applications of Storage Batterise 225
109. Emergency Service 225

ARTICLE PAGE
110. Auxiliary Power Service 226
111. Voltage Regulation 227
112. Vehicle Batteries 229
113. Automobile Starting and Lighting 230
114. Train-lighting Batteries 230
115. Farm-lighting Batteries 231
116. Selection of Proper Size of Farm-lighting Battery 231
117. Radio Batteries 233
118. Miscellaneous 234

INDEX 237

STORAGE BATTERIES

CHAPTER I

THE STORAGE CELL

1. Primary and Secondary Cells.—An *electric cell* is a device for the conversion of chemical energy into electrical energy. It consists of a containing vessel with two unlike plates or rods called electrodes and a solution called the electrolyte, all assembled together and utilized as a source of electricity. Electric cells are either primary or secondary.

A *primary cell* is a cell in which the electrodes and the electrolyte are of such a nature that an electric current will flow as soon as the external circuit is closed. After a period of use either the plates or the electrolyte or both must be renewed. The cell is then said to be exhausted.

A *secondary cell* differs from a primary cell in that the groups of plates and the electrolyte are of such a nature that the activity of the cell may be restored by passing an electric current through it against the electromotive force of the cell. Such a cell is also called an accumulator, but more commonly is known as a storage cell.

In order to exemplify the difference between a primary and a secondary cell we may construct a simple cell, as shown in Fig. 1, with dilute sulphuric acid as the electrolyte and examine its action under each of the following conditions:

(*a*) One plate of copper, the other of zinc.
(*b*) Both plates of lead.

(*a*) With one plate of copper and the other of zinc connected together outside the solution by a piece of wire, we find that an electric current flows through the wire from

the copper plate to the zinc plate and through the solution from the zinc plate to the copper plate. The zinc plate is gradually consumed and the copper plate is not affected. Zinc enters into the solution and replaces hydrogen in the sulphuric acid. The hydrogen appears on the copper plate as a gaseous film and escapes from the solution in the form of bubbles. This film of hydrogen finally covers all or a part of the surface of the copper plate, and as it has insulating properties the flow of current is gradually decreased. This effect is called polarization. Such a cell is unsatisfactory for purposes requiring a constant current. The zinc is not restored to the plate in a regular manner if a current is made to pass in the reverse direction. After a time the cell is exhausted and can be renewed only by replacing

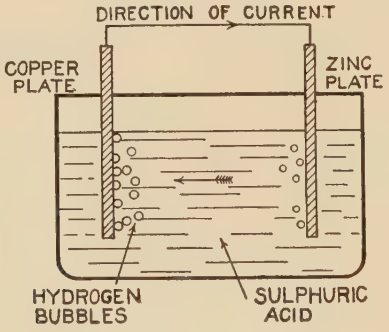


FIG. 1.—A simple primary cell.

some of its elements. These characteristics are typical of a primary cell.

(*b*) When two plates of lead are immersed in the solution of sulphuric acid, no current flows upon the completion of the circuit, as the two plates are alike. They are of the same material, but in order to have an electric cell the plates must be of different materials. However, when a current from an outside source is passed from one plate to the other, the plate at which the current enters (the positive) slowly turns brown in color and the plate at which the current leaves the cell (the negative) turns gray. The brown color is due to the formation of an oxide of lead

called lead peroxide. This brown color is characteristic of the positive plates of all lead storage cells. When the charging current is stopped and the plates are connected together by a wire, it is found that a reverse current flows. This process of charging and discharging may be repeated indefinitely. Such a combination of lead plates and electrolyte is a secondary or storage cell.

2. The Storage Cell.—The lead storage cell consists of a plate of lead and a plate covered with peroxide of lead immersed in a solution of sulphuric acid. It is difficult to conceive of a more simple apparatus. It has not been changed essentially since it was first constructed by Planté in 1860. In 1898, Edison began to develop the storage cell which bears his name. At the present time the only two types in use are:

(*a*) The lead-acid cell.
(*b*) The nickel-iron-alkaline cell.

The former is referred to in these pages as the "lead-acid cell" and the latter is referred to as the "nickel-iron-alkaline" or "Edison cell." The Edison cell is discussed under a special chapter. The two types are both important, but confusion is avoided by treating them separately.

It must be clearly understood that electricity is not "stored" in either the primary or the secondary cell. The decomposition of the plates in the solution is a chemical change which occurs in either the primary or the secondary cell, and this is the cause of the flow of current in a circuit formed by connecting the plates by a piece of wire. No simple explanation of this can be given. In the storage cell, energy is stored in chemical form during charge and released by chemical action in the cell during discharge. Consequently, it is apparent that, in order to understand the storage cell, we must study the chemical and electrical changes during charge and discharge.

3. The Planté Type of Plate.—The first successful storage cells were made by Gaston Planté in 1860. He placed

two sheets of lead in dilute sulphuric acid and after passing a current through the acid from one plate to the other found that a reverse current could be obtained from the combination. He also found that the capacity of the cell for delivering current was increased by repeatedly reversing the direction of the charging current. When this was done, the coating of the surface became deeper and more material on the plates became chemically active. Processes of manufacture, which produce the active material out of the lead of the plate itself, are called "Planté" processes. Because of the cost of electric energy, and the time required to make the coating deep enough to give good capacity by repeated reversals of current, the simple process is no longer employed. Accelerated processes using various chemicals are now used in order to cheapen the cost of manufacture.

4. The Faure or Pasted Type of Plate.—Charles H. Brush and Camille A. Faure, working independently, devised in 1880 a new process for making the plates. In this process the active material is prepared as a paste and applied to a plate or grid. Red lead, an oxide of lead composed of 4 parts of oxygen to 3 of lead, is usually the basis of the paste for the positive and litharge for the negative plates. The red lead is easily converted into lead peroxide and the litharge into sponge lead. Plates made by this pasting process have a large capacity for their weight. They have the disadvantage that the active material or paste easily separates from the grid or plate. Different manufacturers have devised many ingenious methods of shaping the holes or interstices in the plates so as to reduce this tendency. The trouble is aggravated by the fact that the material changes its volume as it is converted from lead to lead sulphate or from lead peroxide to lead sulphate during charge and discharge. This periodic expansion and contraction causes it to free itself from the supporting grid.

5. The Positive Plate.—The active material of the positive plate of a charged lead cell is brown in color and is composed of peroxide of lead. Both the positive and

negative plates of most lead cells are made of a stiff alloy of lead and antimony in the form of a grid which supports the active material. The quantity of antimony ranges from 2 to 12 per cent depending upon the type and the purpose for which the plate is made. The small rectangular spaces shown on the plate in Fig. 2 contain the active material. The ribs of the plate which run both vertically and horizontally serve to stiffen the plate, to support the active material, and to conduct the current from the terminal lug to all parts of the plate.

A pasted positive plate may be made by filling the spaces in the grid with a paste made of red lead (Pb_3O_4 and)

FIG. 2.—Positive plate.

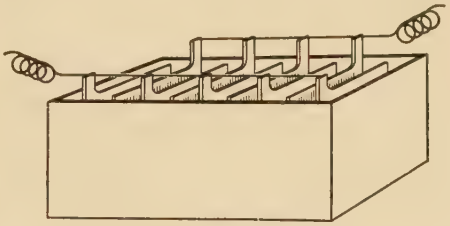


FIG. 3.—Forming tank.

dilute sulphuric acid. After this has hardened, the plate, together with a negative one, is placed in dilute sulphuric acid and a current is caused to pass into it from some outside source and to the other plate through the solution, Fig. 3. This converts the red lead into peroxide of lead.

6. The Negative Plate.—The active material of the negative plate of a charged cell is gray in color and is composed of sponge lead. Practically all negative plates are of the pasted type. Litharge, which is an oxide of lead consisting of one part of lead and one part of oxygen, may be made into a paste with sulphuric acid and pressed into the openings of a supporting grid made of a lead-antimony alloy. There are many formulas for the composition of the paste. Some manufacturers mix a soluble salt with the paste in order to insure porosity. Others mix graphite with the paste. As the paste dries it changes to sulphate and cements itself to the grid. When plates made in this

manner are assembled in a cell and a charging current is applied, the litharge and sulphate are converted into a tough and coherent mass of sponge lead. A plate made in this way gives good satisfaction and outlasts the positive plates, Fig. 4.

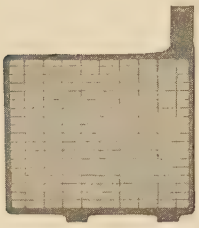


Fig. 4.—Negative plate.

While the outline given of the manufacture of the plates appears to be a very simple process, the amateur should not be misled into attempting to make his own plates. When new plates are required, they should be obtained from a manufacturer.

7. The Positive Group.—A number of positive plates assembled and connected together for use in a cell constitute a positive group, Fig. 5. The number of plates in a positive group is generally made one less than the number of plates in a negative group. When these are dovetailed with a negative group, there is a negative plate on each side of each positive plate. This equalizes the action on both sides of the positive plates and tends to prevent the distortion and buckling which would otherwise occur due to unequal expansion of the active material.

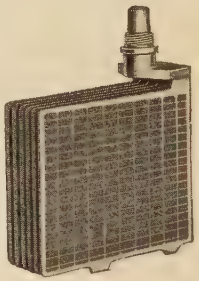


Fig. 5.—Positive group.

8. The Negative Group.—A number of negative plates assembled and connected together for use in a cell constitute a negative group, Fig. 6. In both positive and negative groups the plates are connected to a strap by an extension from the top of the plate called a lug. In sealed cells that portion of the strap which extends through the cover of the cell by means of which connection is made to other cells or circuits, is called the post.

Fig. 6.—Negative group.

9. Separators.—Separators are thin sheets of wood, Fig. 7, sheets of perforated or threaded hard rubber, Fig. 8, or glass rods which are

inserted between the positive and the negative plates in order to keep them from coming into contact. Wood separators are treated in order to eliminate all traces of acetic acid. They must be carefully kept in a weak solution of electrolyte until they are ready for use. In case they are grooved on one side, this side is placed next the positive plate. Wood and hard rubber separators are commonly used in portable cells. Glass rods were formerly used in large central station cells; now wood separators are generally employed.

It might appear that these separators would prevent the passage of current between the positive and negative plates. An electric current will, however, pass through any porous

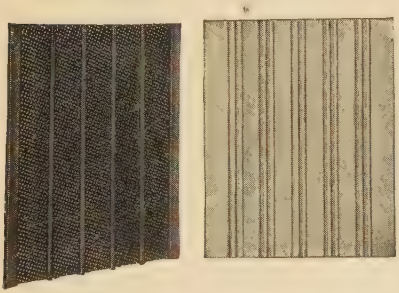


FIG. 7.—Wood separators.

FIG. 8.—Rubber separator

diaphragm or plate in the solution. The Daniell primary cell, in which the plates are placed in separate compartments with a porous earthenware partition between them, is an example of the fact that the electric current passes through such a partition.

10. The Electrolyte.—The electrolyte for the lead cell is sulphuric acid diluted with distilled water or water which upon analysis is shown to contain no deleterious ingredients. The electrolyte is the solution which carries the current and which is decomposed by it. The electrolyte is prepared by mixing sulphuric acid with the water until the desired density is reached. Sulphuric acid

is heavier than water; hence, if the water is poured on top, it will not mix readily. The water will form a layer over the acid and the resulting chemical action may develop enough heat to convert some of the water into steam. The escaping of this steam may spatter the mixture over the face or body of the mixer and produce severe burns. To avoid this danger, *always pour the acid into the water and stir the mixture continually while so doing.* The heat generated will also be dissipated more quickly if the solution is stirred for some time after all of the acid has been poured in.

The electrolyte should be prepared in a glass or glazed earthenware jar or in a lead lined tank. Iron or enameled vessels are likely to be attacked by the acid, and any impurities introduced into the acid will be harmful to the cell. A glass or wooden rod may be used for stirring the solution.

11. Specific Gravity.—The weight of any substance compared with the weight of an equal volume of water is called its specific gravity. Thus if a certain volume of water weighs 1 lb. and an equal volume of acid weighs 1.250 lb., then the specific gravity of the acid is 1.250. This is usually spoken of as twelve hundred fifty, in which case water would be spoken of as having a specific gravity of ten hundred. If the specific gravity of the electrolyte changes from say 1.250 to 1.251 or from 1,250 to 1,251, it is said to have changed one point.

The term density is often used in practice for specific gravity. Thus the density of concentrated sulphuric acid, or its specific gravity, is 1.835. Commercial acid used in storage cells usually has a density of 1.400. When acid of this density is mixed with an equal volume of water, we would expect the density of the resultant solution to be 1.200, since this is the result obtained by adding 1.400 and 1.000 and dividing by two, the new volume being assumed to be twice as great. This is not exactly the case, however, for the same reason that a quart of salt and a quart of water do not make 2 quarts. There is a slight shrinkage

in volume when sulphuric acid and water are mixed together. Table I shows the specific gravity of the solution when one part of sulphuric acid of 1.835 specific gravity at 60 deg. Fahr. is mixed with the volume of water indicated.

TABLE I.—SPECIFIC GRAVITY OF SULPHURIC ACID SOLUTIONS

Specific gravity of solution (70 deg. Fahr.)	Parts of water to one part acid		Percentage of sulphuric acid in solution
	By volume	By weight	
1.100	9.8	5.4	14.65
1.110	8.8	4.84	16.0
1.120	8.0	4.4	17.4
1.130	7.28	3.98	18.8
1.140	6.68	3.63	20.1
1.150	6.15	3.35	21.4
1.160	5.7	3.11	22.7
1.170	5.3	2.9	24.0
1.180	4.95	2.7	25.2
1.190	4.62	2.52	26.5
1.200	4.33	2.36	27.7
1.210	4.07	2.22	29.0
1.220	3.84	2.09	30.2
1.230	3.6	1.97	31.4
1.240	3.4	1.86	32.5
1.250	3.22	1.76	33.7
1.260	3.05	1.66	35.0
1.270	2.9	1.57	36.1
1.280	2.75	1.49	37.3
1.290	2.6	1.41	38.5
1.300	2.47	1.34	39.65
1.320	2.24	1.22	42.0
1.340	2.04	1.11	44.1
1.360	1.86	1.01	46.3
1.380	1.7	0.92	48.4
1.400	1.56	0.84	50.5
1.500	1.0	0.55	60.15
1.600	0.639	0.348	69.12
1.700	0.369	0.201	77.6
1.800	0.1192	0.0646	87.5
1.835	0.0	0.0	93.19

12. Hydrometer or Acidimeter.—The specific gravity of the electrolyte is determined by means of an instrument called a *hydrometer*. The term *acidimeter* is a logical name for the same instrument, but it is not generally used. The hydrometer is a graduated glass tube weighted at the bottom, Fig. 9, so that it will float in a vertical position at

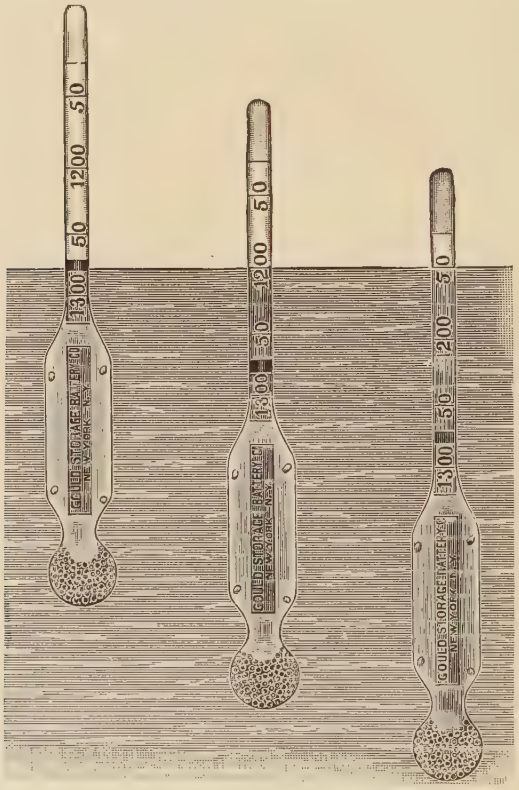


Fig. 9.—Hydrometers.

depths depending on the density of the electrolyte. The mark on the scale at the surface of the liquid shows the specific gravity. The hydrometer is frequently placed inside of a glass tube provided with a rubber bulb in which form it is known as a hydrometer syringe, Fig. 10. This syringe enables the operator to draw sufficient electrolyte up

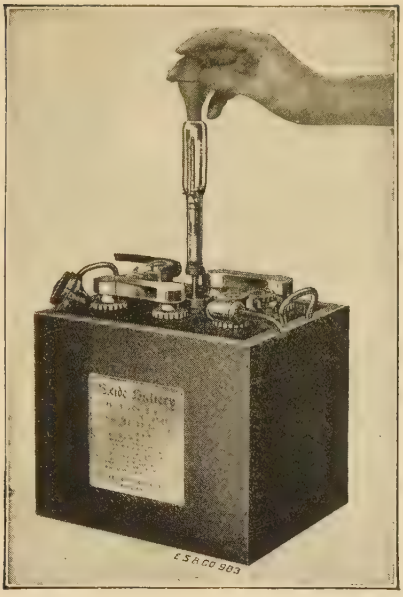


FIG. 10.—A hydrometer syringe.

TABLE II.—RELATIONS OF BAUMÉ AND SPECIFIC GRAVITY SCALES

Degrees Baumé	Specific gravity	Degrees Baumé	Specific gravity
0	1.0000	19	1.1508
1	1.0069	20	1.1600
2	1.0140	21	1.1694
3	1.0211	22	1.1789
4	1.0284	23	1.1885
5	1.0357	24	1.1983
6	1.0432	25	1.2083
7	1.0507	26	1.2185
8	1.0584	27	1.2288
9	1.0662	28	1.2393
10	1.0741	29	1.2500
11	1.0821	30	1.2609
12	1.0902	31	1.2719
13	1.0985	32	1.2832
14	1.1069	33	1.2946
15	1.1154	34	1.3063
16	1.1240	35	1.3182
17	1.1328	36	1.3303
18	1.1417	37	1.3426

into the glass tube to float the hydrometer and renders it possible to read the scale with greater convenience.

The specific gravity of liquids is sometimes expressed in terms of an arbitrary scale on the hydrometer. The most common of these scales is the Baumé. Table II gives the relation between the two scales.

Fig. 11. Battery thermometer.

13. Effect of Temperature on the Specific Gravity.—Due to the well-known property of expansion with rise in temperature, a hot solution occupies more space than a cool solution and, consequently, the specific gravity of the electrolyte is less when hot than when cold. An electrolyte which has a specific gravity of 1,253 at 60 deg. Fahr. will have a specific gravity of 1,250 at 70 deg. Fahr. *For each three degrees of temperature of the electrolyte above* 70 *deg. Fahr. add one point, to the observed reading, and for each three degrees of temperature below* 70 *deg. Fahr. deduct one point from the observed reading, and the result will be the specific gravity at* 70 *deg. Fahr.* Thus if the temperature of the electrolyte is 100 deg. and the specific gravity is 1,240, the corrected reading for a temperature of 70 deg. is 1,250, ten points higher, as the temperature is 30 deg. higher. The specific gravity of the electrolyte is always reduced to the value that it would have if its temperature were 70 deg. Fahr., since 70 deg. is adopted by common consent as the standard reference temperature.

The temperature of the electrolyte is taken with a battery thermometer. A battery thermometer is exactly like an ordinary thermometer, but it may have a special scale which shows how much to add to or deduct from the observed hydrometer reading in order to correct it for a normal or standard temperature of 70 deg. The thermometer shown in Fig. 11 with the temperature at 88 deg. shows a reading on the right-hand scale of plus

6. This means that 6 points must be added to the reading of the hydrometer in order to obtain the correct specific gravity at the standard or normal temperature of 70 deg.

14. General Assembly of the Lead Cell.—All cells are composed of a group of positive plates which are sandwiched or dovetailed between a group of negative plates. One positive group, one negative group, and the separators

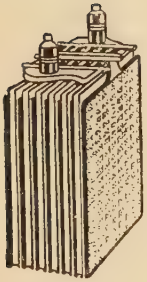


FIG. 12.—A cell element.

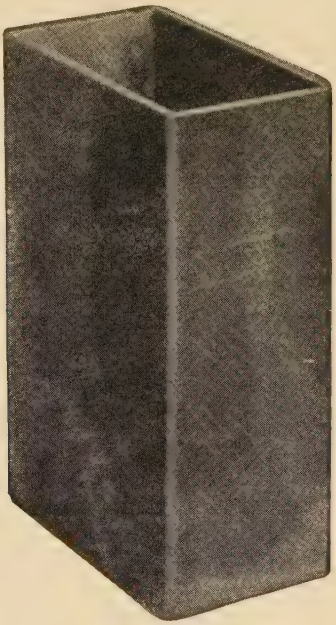


FIG. 13.—Hard rubber jar.

between them are called an element, Fig. 12. Each element is immersed in its own containing jar. The jars for cells intended for portable use, such as automobile batteries, are constructed of hard rubber or similar composition, Fig. 13. Small stationary cells are frequently assembled in glass jars. Lead-lined wooden tanks are usually used for the large stationary types of cells. Glazed earthenware jars have been tried but have not proved successful in practice, due to imperfections which appear in the glaze.

The plates are always placed vertically in the jars. If they were placed horizontally, the gas which is evolved

would not escape readily, and the active material which is shed in operation would have no chance to fall to the bottom of the jar, and short-circuits would result. The plates are never allowed to rest directly on the bottom of the jars but are supported on raised ridges from the bottom, or hung

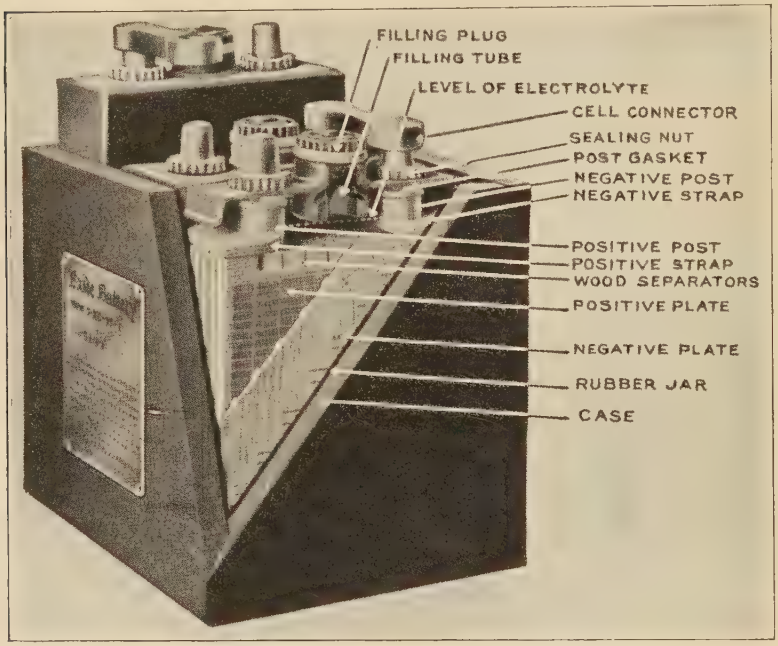


FIG. 14.—A vehicle battery assembly.

from the edges by extended lugs. Such supports provide a space at the bottom for the accumulation of sediment. Figure 14 shows how the plates of a vehicle battery are assembled.

RECAPITULATION

1. An *electric* cell is a combination of a container, an electrolyte, and two electrodes of dissimilar material. Electric cells are of two kinds, (*a*) primary, (*b*) secondary or storage.

(*a*) A *primary* cell is one in which the electrical energy is liberated by the chemical action between the electrolyte and one or both of the electrodes. The chemical action is a primary or immediate source of the electric current.

(*b*) A *secondary* or *storage* cell is a combination of electrodes, electrolyte, and container in which the chemical action between the electrodes and electrolyte is converted into electrical energy; and when the active material on the electrodes has been changed by chemical action to an inactive form, it may be reconverted into its original or active form by the passage of an electric current through the cell against its e.m.f. The common storage cells are the lead-acid and the nickel-iron-alkaline types.

2. The elements of a cell are the electrolyte and the electrodes. The electrodes of the lead-acid cell are plates of lead peroxide for the positive, and sponge lead for the negative. The electrolyte is dilute sulphuric acid.

The electrodes of the nickel-iron-alkaline cell are a steel framework with iron-oxide for the negative and nickel-hydrate for the active material of the positive. The electrolyte is potassium hydroxide.

3. An *electrolyte* is a liquid conductor which is decomposed by the passage of an electric current throught it.

4. *Polarization* is the development of a counter electromotive force in an electric cell by the current of the cell. In a simple cell this is usually due to a film of hydrogen which the current deposits on the positive electrode.

5. By *charging a storage cell* is meant the forcing of a current through it against its e.m.f. This current produces chemical changes which restore the materials to the same condition they had before the discharge; that is, to a condition which enables the cell to deliver a current. No electricity is stored in a storage cell.

6. *Planté plates* are those on which the active material is formed from the plates themselves.

7. The *Faure or pasted plates* are those for which the active material is prepared separately in the form of a paste and then applied to the grid of the plate.

8. *Separators* are thin sheets of corrugated wood or porous rubber which are inserted between the positive and negative plates.

9. When mixing the electrolyte, always pour the acid into the water, *never* the water into the acid.

10. *Specific gravity* is the relative weight of a given volume of a substance as compared with the weight of the same volume of water. The specific gravity of pure sulphuric acid is 1.835.

11. A *hydrometer or acidimeter* is a glass tube weighted at one end, and graduated with a convenient scale. The depth to which it will sink into a liquid is a measure of the liquid's specific gravity.

12. The specific gravity of liquids decreases with an increase in temperature and increases with a decrease in temperature. The standard temperature for the specific gravity of the lead-acid cell electrolyte is 70 deg. Fahr., and the increase or decrease in density is 0.0003 per degree.

QUESTIONS

1. Distinguish between primary and secondary cells.

2. (*a*) What are the electrodes of a cell?

(*b*) What is the electrolyte?

3. What causes polarization of a cell? Does a storage cell polarize?

4. If we have a primary cell whose electrodes are copper and zinc and whose electrolyte is dilute sulphuric acid, in which direction does the current flow in a wire connecting the copper and zinc? In which direction does the current flow through the electrolyte? Which is the positive and which the negative terminal of the cell?

5. If two electrodes of the same material are used in a cell, will there be any electrical pressure between them? Will such a cell deliver an electric current to an external circuit?

6. If you make a cell of zinc, copper, and water, will there be any current delivered to a wire connecting the electrodes?

7. What must be the nature of the electrodes and liquid before the cell will deliver a current?

8. Do the elements composing a storage cell fulfill these conditions? Explain.

9. (*a*) If two pure lead plates are used for the electrodes and dilute sulphuric acid is used for the electrolyte, will the combination deliver current to a wire connecting the two plates?

(*b*) How can the two plates be made dissimilar so that the combination will produce a current when the two plates are connected?

10. What are the two common forms of storage cells?

11. (*a*) Is electricity stored in a storage cell any more than in a primary cell?

(*b*) State briefly what takes place when the lead cell is charged.

12. What is meant by Planté plates, and the Planté process of making plates?

13. Explain how pasted plates are made. What materials are used?

14. When lead or lead peroxide is converted into lead sulphate, what physical change takes place? What effect will this change have upon the adhesion of the active material to the grids?

15. What is the relative number of positive and negative plates used in a cell? Why?

16. Why are separators used and of what are they made?

17. (*a*) Does the electric current in passing through a metallic conductor decompose it?

(*b*) What effect does the passage of a current through an electrolyte have upon its composition or structure?

18. Distinguish between electrolytic conduction and metallic conduction.

19. (*a*) Does pure water conduct electricity readily?

(*b*) Does pure sulphuric acid conduct electricity readily?

20. Of what materials is the electrolyte of lead storage cells made?

21. Take a small test tube and fill it about one-third full of water, then pour in about a thimbleful of sulphuric acid. Feel of the tube; does it get warm? What is developed when water and sulphuric acid are mixed?

22. Explain what precautions must be observed in preparing the electrolyte. Why not use metallic vessels for mixing the electrolyte? May spring or artesian water be used for the electrolyte? Why?

23. (*a*) What is meant by specific gravity?

(*b*) Which is heavier, a gallon of water or a gallon of sulphuric acid? How many times as heavy?

24. When we say that the specific gravity of sulphuric acid is 1.835, what is meant?

25. Why is it necessary to specify the temperature of the electrolyte in connection with its specific gravity or density?

26. Three parts of water and one of sulphuric acid are mixed. What is the density of the solution at 70 deg. Fahr.?

27. Which form of hydrometer will be more accurate, one with a stem of large diameter or one with a stem of small diameter? Explain.

28. What is the percentage of sulphuric acid, density 1.835, in an electrolyte whose density is 1.300? What are the relative volumes of water and sulphuric acid?

29. The density of an electrolyte at a temperature of 85 deg. Fahr. is 1.125. What is its density at 70 deg. Fahr.?

30. The reading on a Baumé hydrometer is 31 at 60 deg. Fahr., what is the specific gravity of the solution at 70 deg. Fahr.?

31. You wish to make an electrolyte whose density at 70 deg. Fahr. shall be 1.280. The temperature of the water and sulphuric acid is 95 deg. Fahr., how many parts of acid and water will you use?

32. Describe a battery thermometer.

CHAPTER II

FUNDAMENTAL ELECTRICAL QUANTITIES AND METERS

15. General.—As already pointed out, a storage cell is merely a device in which the energy of the electric current on charge produces a chemical reaction and then when a current is taken from the cell another chemical reaction takes place reconverting the energy. The electrical quantities involved in this transformation are electromotive force, electric current, and resistance. These and their relations are discussed in this chapter.

16. Electromotive Force or Electrical Pressure.—To cause a current of water to circulate through a system of pipes, a mechanical pressure must be applied. In an analogous way an electrical pressure is necessary to cause an electric current to flow through a circuit of wires. The cause of the electric current is an electromotive force which may be produced in several ways. Just as it is necessary to know the magnitude or intensity of the mechanical pressure that forces the water through the pipes, so it is necessary to be able to measure the electromotive force. In order to do this, units are necessary. The pound is the unit in which the magnitude of the mechanical pressure is expressed, and similarly the unit of electrical pressure is the *volt*. The volt has been defined in terms of the ampere and the ohm. These will be defined later. The magnitude or intensity of the electromotive force of electric cells depends upon the materials of which they are made. A Daniell cell, which is made of copper in copper sulphate and zinc in zinc sulphate, has an e.m.f. (electromotive force) of about 1.08 volts. A fresh dry cell has an e.m.f. of about 1.5 volts. The voltage of the ordinary house-

lighting circuit is about 110 volts, and that of some high-tension transmission lines 150,000 volts.

17. Sources of Electromotive Force.—An electromotive force may be produced in several ways, the three common ones being (*a*) chemical action, (*b*) electromagnetic induction, and (*c*) thermo-electric conversion.

(*a*) *Chemical Action.*—When dissimilar substances such as copper and zinc are placed in dilute acid but separated from each other, the chemical action of the acid develops an electromotive force between the copper and the zinc. This is typical of all electric cells.

The following table gives the e.m.f. of various types of cells for reference:

	Volts
Bunsen	1.75 to 1.95
Chloride of silver	1.1
Daniell	0.98 to 1.08
Dry Cell	1.4
Edison-Lalande	0.7
Grove	1.75 to 1.95
Leclanche	1.4 to 1.6
Weston standard cell	1.01830
Lead-acid storage cell	2.1
Nickel-iron-alkaline storage cell	1.2

(*b*) *Electromagnetic Induction.*—At first electric currents were obtained from batteries of electric cells. The discovery was later made that a magnetic field surrounds a wire in which an electric current is flowing, and that this magnetic field is due to the current itself. Many years passed before it was realized that this phenomenon is reversible, or, in other words, that an electric current will flow in a loop of wire when a magnetic field is suddenly built up inside of the loop, or when the opposite sides of the loop are made to cut the magnetic field in opposite directions. The field may be stationary and the circuit may be moved or the circuit may be stationary and the field be moved. In either case an electromotive force is set up which will cause a current to flow through any circuit to which it is connected.

The mere insertion of a permanent magnet in a coil of wire produces an e.m.f. in the coil, and a current if the circuit be closed. The withdrawal of the magnet produces an e.m.f. and a current in the reverse direction. It is evident that exactly the same effects are produced when the coil is slipped over the pole of a magnet. The generation or development of an electromotive force by the relative motion of a conductor and a magnetic field is electromagnetic induction. It is the fundamental principle of all electrical machines.

(*c*) *Thermo-electric Conversion.*—When, for example, a piece of iron wire is connected to one terminal of a sensitive electrical instrument, such as a galvanometer, and a piece of copper wire is connected to the other terminal, the instrument can be made to deflect by twisting the free ends of the wires together and heating the junction with a lighted match. The increase of temperature of the junction produces a minute e.m.f., and a small current flows in the circuit. With such a device the heat is converted directly into electrical energy. This principle has wide application in temperature measurements and the study of radiation phenomena. It is not used for the generation of an electric current for power.

18. Electric Current.—In a preceding paragraph, electrical pressure was compared with the mechanical pressure necessary to make a current of water circulate through pipes. By analogy, when an electrical pressure is applied to the two ends of a wire a state or condition is set up around the wire which is explained by the statement that an electric current is flowing through the wire. If the wire be cut and a motor, or an electric lamp, be connected to the ends thus formed, and the electrical pressure is high enough, the motor will do work or the lamp will light up. This is explained by saying that energy is transferred from the source of e.m.f. to the motor, or lamp, by a current of electricity in the wires. This is plainly analogous to the transfer of energy by a current of water from a pump to a water motor. To make the analogy more exact, the water

after leaving the motor should be returned by another pipe to the pump. There is no name for a unit current of water, but for the sake of completing our analogy we may define a unit current of water as that current which delivers one gallon of water in one second, and call this unit a "hydra." In an electric circuit the unit current is called the *ampere*. An ampere is that current which delivers, or transfers, one coulomb of electricity in one second. Another definition of the ampere will be given in connection with Faraday's laws.

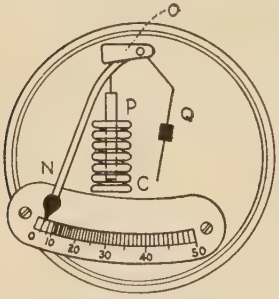


FIG. 15.—Principle of plunger type ammeter.

19. Measurement of Electric Current.—The intensity of an electric current can be measured by any one of several of its effects which is proportional to its magnitude. The instrument used for measuring the current is called an *ammeter*. Among the more common effects that may thus be used are its electrolytic, magnetic, and heating effects. The electrolytic action of the current and its importance will be explained later. Commercial instruments for measuring current make use of the magnetic effect.

A current-carrying wire is surrounded by a magnetic field whose intensity is proportional to the current. The presence of the field is easily shown by bringing a compass needle near the wire. If this be done, the magnetic field around the wire reacts with the magnetic field of the compass needle causing it to deflect. If the coil and needle are properly arranged, the resulting deflection of the compass needle will be a measure of the current in the wire. The force exerted by the current can be greatly increased by winding the wire into a solenoid within which is a movable iron core as shown in Fig. 15. The iron core is attached to a pivoted pointer, N, and, as the current in the solenoid increases, the increased magnetic force draws the iron core downward. The resulting deflection is a measure of the current. A commercial instrument which operates on this

principle is shown with dial removed in Fig. 16. The graduations are numbered to correspond with the number of

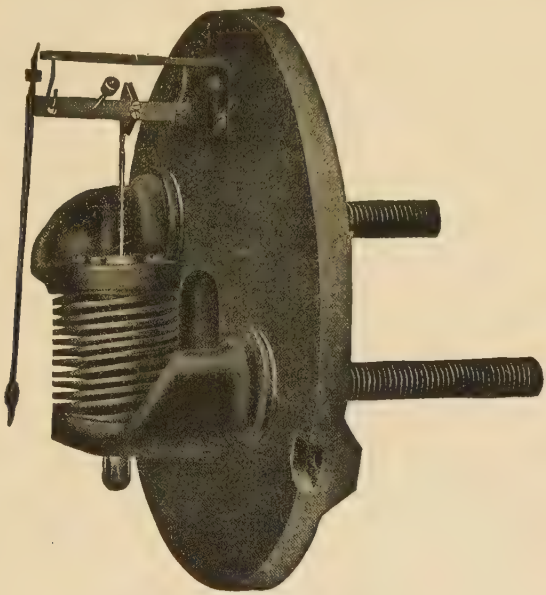


Fig. 16.—A plunger type ammeter.

amperes required to produce the deflection. The same result may be secured in different ways, but for direct-

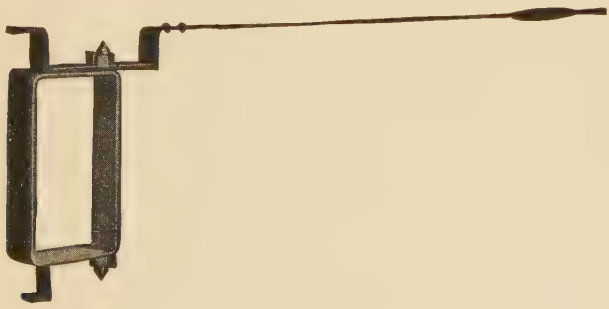


Fig. 17.—Movable element of permanent magnet ammeter.

current measurements it is customary to mount a coil, Fig. 17, on a spindle and pivot it between the poles of a permanent magnet, Fig. 18. When such a construction is employed,

the direction of the deflection reverses when the direction of current flow is reversed.

The familiar "Charge Indicator" on the dashboard of an automobile is essentially a coil of wire carrying the battery current with a movable permanent magnet to give the indication. When the current is in a certain direction, for example, during charge, the magnetic field set up by the coil attracts the north pole of the magnet and repels the south pole. During discharge the action is reversed.

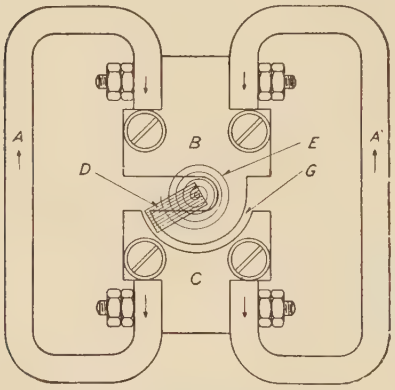


FIG. 18.—A permanent magnet movable-coil instrument.

The use of an *ammeter shunt* is very common on all switchboards. This device is simply a very low resistance of special alloy, capable of carrying the large current of the installation without overheating, and connected in the circuit at a convenient point. The ammeter proper is located at a convenient place on the switchboard and connected to the shunt by a pair of wires which are supplied with the meter and are a part of it. The length of these wires should not be changed, but any excess may be neatly coiled and located back of the board. The relative resistances of the shunt and of the instrument are such that about $\frac{1}{10,000}$ of the total current passes through the instrument. The scale of the instrument is marked for the full amount of the current.

20. Ampere-hour Meter.—The ampere is defined as the current that transfers one coulomb in one second. If a current of one ampere flows for one hour, the quantity of electricity transmitted is called an *ampere-hour*. Thus an ampere-hour is the quantity of electricity conveyed by one ampere in one hour. In charging storage batteries both the current and the quantity of electricity are important. This will be discussed more fully later.

An instrument that registers the quantity of electricity that has passed through a circuit is called an *ampere-hour meter*. The essential elements of the Sangamo ampere-hour meter, the type used most extensively in this country, are shown in Fig. 19. The operating element is a rotatable disk mounted on pivots above the poles of a

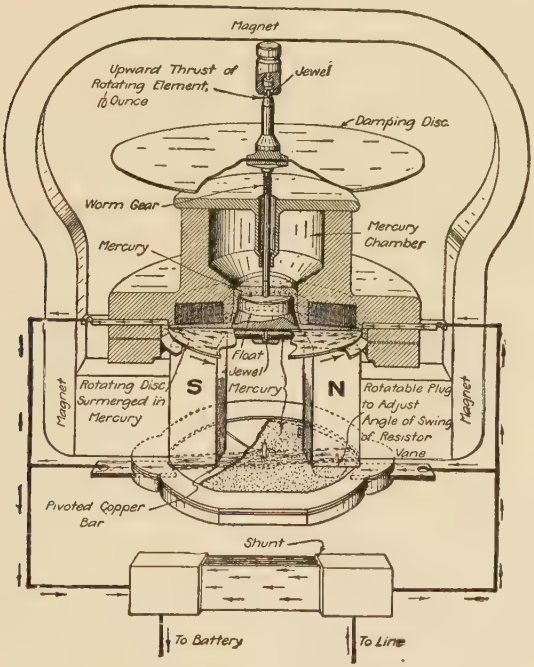


FIG. 19.—Elements of an ampere-hour meter.

permanent magnet, *N S*. The direction of current flow through the mercury chamber and disk is shown by arrowheads. The reaction between the magnetic field surrounding the current and the magnetic field of the permanent magnet produces a torque on the disk which is proportional to the current flowing. By means of a worm on the shaft and a recording train of gears the number of rotations, in any given time, is indicated. Since the torque on the disk is proportional to the current, the number of rotations is proportional to the quantity of electricity that

passed through the meter in the time interval. The dial is graduated in ampere-hours.

The usefulness of such a meter in storage battery work is apparent. As the battery is charged, the meter records the ampere-hours which have passed until the battery is full, and then, on discharge the meter runs in the opposite direction, so that the state of charge is always shown on the dial. Because of the fact that the input of a battery is always greater than the output, the meter is adjusted to run more slowly during charge than during discharge. By means of such a meter, a careful operator can keep track of the exact condition of the battery at all times. Whenever the battery is charged until it gasses freely with a small charging current, the ampere-hour meter should be set to show full charge in the cells.

21. Voltmeter.—The *voltmeter* is an instrument used to measure electromotive force, or drop in potential. Its principle of operation is identical with that of an ammeter, but the coils are wound with many more turns of much finer wire. A very small current passes through it, but due to the large number of turns of wire the force tending to deflect the pointer is adequate for the purpose. The voltmeter is connected in multiple with the circuit whose e.m.f. it is desired to determine. If an ammeter were connected in the same manner, it would probably be ruined as its electrical resistance is so low that an excessive current would flow through it and burn out its coils. The current which passes through the coils of the ordinary voltmeter at full scale deflection is only about $\frac{1}{100}$ ampere or less.

22. Resistance.—Just as some energy is wasted in forcing a current of water against the frictional resistance of the pipes, so when an electric current is flowing through or along a wire some of the energy is wasted by a property of the wire. This property of a conductor by means of which some of the energy of the current is converted into heat is called its electrical resistance. The effect of resistance may be looked upon in another way. In forcing a current through an electric circuit, some of the pressure is

utilized in overcoming the effect of the resistance, and so it is customary to define resistance as that property of a conductor which opposes the flow of an electric current. The unit of resistance is the resistance offered by a column of mercury 106.3 cm. (41.73 in.) long and one square millimeter (0.00155 sq. in.) in section at 32 deg. Fahr. This unit is called the *ohm*. One thousand feet of No. 10 A.W.G. copper wire at a temperature of 68 deg. Fahr.

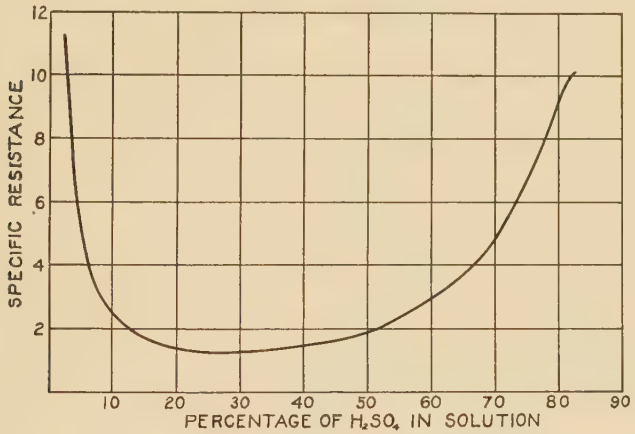


FIG. 20.—Variation of resistivity of electrolyte.

has about one ohm resistance. The electrical resistance of a conductor depends upon the material of which it is made, its length, and cross-sectional area. This relation is usually expressed by the formula

$$R = \frac{rl}{A}$$

which translated into words means that the resistance of a conductor is equal to the product of the resistivity of the material, r, by the length, l, of the conductor, divided by its cross-sectional area. For practical calculations, r is the resistance of a wire of the material one foot long and one mil (0.001 in.), in diameter. l is the length of the conductor in feet and A is the cross-sectional area in circular mils (diameter squared). The mil foot resistivity of copper is about 10.4 ohms at 68 deg. Fahr. The resistivity of lead

is about 134 ohms at the same temperature. The relation expressed by the above formula holds for liquid as well as solid conductors. The electrolyte of a storage cell is a conductor and, hence, its resistance may be calculated by the foregoing formula, provided the resistivity is known. This varies widely with the percentage of acid in the solution. This variation is shown by the curve, Fig. 20. Table III gives some copper wire data that may be useful to one who has charge of storage batteries.

TABLE III.—COPPER WIRE TABLE

Gauge A.W.G.	Diameter	Feet per ohm	Ohms per 1,000 ft.
2	0.2576	6,314.0	0.1584
3	0.2294	5,008.0	0.1997
4	0.2043	3,971.0	0.2518
5	0.1819	3,149.0	0.3176
6	0.1620	2,497.0	0.4004
7	0.1443	1,981.0	0.5048
8	0.1285	1,571.0	0.6367
9	0.1144	1,246.0	0.8028
10	0.1019	987.8	1.012
11	0.09074	783.6	1.276
12	0.08081	691.2	1.610
13	0.07196	492.7	2.029
14	0.06408	390.7	2.559
15	0.05707	309.8	3.227
16	0.05082	245.7	4.070
17	0.04526	194.6	5.132

23. Ohm's Law.—A definite relation exists among the three factors, electromotive force, current, and resistance, whereby the value of any one of the factors may be calculated if the other two are known. This relation is known as *Ohm's law* which may be expressed as follows:

The current strength in amperes in any circuit where the current is steady in value equals the electromotive force in

volts divided by the electrical resistance in ohms. In other words, the current increases with the voltage in a circuit of fixed resistance and decreases in value whenever the resistance increases.

24. Voltage Drop.—When a current flows through a conductor, some e.m.f. or voltage is used in forcing the current against the resistance. By Ohm's law this is equal to the product of the current flowing times the resistance of the conductor. If two points on a conductor are some distance apart, that portion of the conductor between the two points has some resistance. The product of the current by this resistance is the voltage drop between the two points.

EXAMPLES

1. It is desired to find the value of the current which flows when a circuit consisting of 100 ft. of No. 10 copper wire is connected to a 6-volt battery.

The resistance of 100 ft. of No. 10 copper wire is found from the wire table to be practically $\frac{1}{10}$ ohm, since the resistance of 1,000 ft. is practically 1.0 ohm. Dividing 6 volts by 0.1 ohm we get 60 amp.

2. It is desired to find the voltage required to cause a current of 5 amp. to flow through a No. 14 wire 200 ft. in length.

The resistance of a No. 14 copper wire is practically 2.5 ohms per 1,000 ft., or $\frac{1}{2}$ ohm for 200 ft. Consequently, the required voltage is found by multiplying $\frac{1}{2}$ ohm by 5 amp., giving 2.5 volts, the desired result.

The fact that Ohm's law applies only to circuits in which the current is steady is to be emphasized. If the current is alternating in character, as in many commercial circuits, the fact that there is a building up of a magnetic field first in one direction and then in another must be taken into consideration. The fluctuation of the current produces opposing voltages which modify the law. This effect need not be considered in storage battery work.

25. Change of Resistance with Temperature.—The resistance of most conductors changes with the temperature. The resistance of pure metallic conductors increases with increase in temperature. For pure metals the increase per ohm per degree is practically the same for all. This

increase per ohm per degree change in temperature is called *temperature coefficient of resistance*, and for copper it is nearly 0.00393 per ohm per degree centigrade at 20 deg. Cent. (68 deg. Fahr.). The resistance of a conductor at any temperature t deg. Cent. is given by the following:

$$R_t = R_{20}[1 + a(t - 20)]$$

R_{20} is the resistance of conductor in ohms at 20 deg. Cent., a the temperature coefficient, and t the temperature, in deg. Cent. For the Fahrenheit scale the expression for copper wires is

$$R_t = R_{68}[1 + 0.00218(t - 68)]$$

The resistance of most alloys also increases with increase in temperature, but to a much smaller extent than pure metals. Thus an alloy of 84 parts by weight of copper, 12 parts by weight of nickel, and 4 parts by weight of manganese, called manganin, has a temperature coefficient of resistance which is negligible for practical purposes. Although the temperature coefficient of manganin is very slight, it is positive between 0 deg. and about 50 deg. Cent. When the temperature is increased above 50 deg. Cent., the resistance of manganin slightly decreases.

Carbon and all electrolytes have negative temperature coefficients of resistance. That is, the resistance of these decreases as the temperature increases. The resistance of the electrolyte of a storage cell is less when warm than when cold.

26. Power.—In everyday usage, the word power has many different meanings. It is often confused with work. Power is not work, but the time rate of doing work. As an illustration suppose that one man carries 2,000 bricks to the second story of a building in 1 day while it takes another man 2 days to do the same work. Evidently, the total amount of work done in the two cases is the same although the rate at which the work is done is different. The second man's rate of doing the work is only one-half that of the first man's rate. Technically, this is explained by saying that the powers of the two men are different. The power

of the first man is double that of the second man. Power is, then, the amount of work done in some unit of time. In engineering practice the unit of time is usually the minute or second. The unit in which electrical power is measured is the *watt*. The watt is the work done by a current of one ampere under a pressure of one volt in one second. The watt is a small quantity; so for practical calculations, the unit of power is 1,000 watts called the *kilowatt*.

The product of amperes and volts in a circuit gives the watts. Since by Ohm's law, the volts equal the product of the amperes and the ohms, it is evident that the watts are also equal to the product of the amperes by the amperes and by the ohms. For example, if we take a circuit in which 60 amp. are flowing through a resistance of 0.1 ohm under a pressure of 6 volts, the watts may be found by multiplying 60 amp. by 6 volts, giving 360 watts, or by multiplying 60 amp. by 60 amp. by 0.1 ohm, giving 360 watts.

In English units the *horsepower* is the unit of power. A horsepower is equal to 550 ft.-lb. per second, or, in other words, it may be defined as the rate at which work is being done when a weight of 1 lb. is raised vertically at the rate of 550 ft. per second. One horsepower equals 746 watts; and *vice versa*, one kilowatt equals about 1⅓ hp.

27. Work and Energy.—The storage cell is a storehouse of energy which under proper conditions may be used to do useful work. The units in which energy and work are measured are the same. In electrical calculations the practical unit of energy is the *kilowatt-hour*. It is the energy converted or utilized in 1 hour when the power is 1 kilowatt. The energy that has been consumed in a circuit in kilowatt-hours equals the power in kilowatts by the time in hours.

EXAMPLE

A certain 6-volt starting battery weighs 60 lb. and will give out 125 ampere-hours at a pressure of 2 volts. Calculate the height to which this battery could raise itself if its stored energy could be used for this purpose.

SOLUTION

The output of the battery in watt-hours is equal to the product of the volts by the ampere-hours, which is $6 \times 125 = 750$ watt-hours. One horsepower hour is equal to 746 watt-hours; then the output in horsepower hours equals $750 \div 746 = 1$ (about). One horsepower hour is equal to $550 \times 60 \times 60 = 1{,}980{,}000$ ft.-lb. Thus the elevation to which the energy of the battery could lift 1 lb. is 1,980,000 ft.; but as the battery weighs 60 lb., it is capable of lifting itself only $\frac{1}{60}$ of this distance, which is 33,000 ft. This is the equivalent of a little over 6 miles. While this seems like a great distance, the energy per pound of the battery is comparatively low when compared with other sources of energy. The energy in a pound of coal is 300 times as great, and even under the inefficient conditions of energy conversion in steam engines, the available energy is thirty or more times as great.

The storage cell is not, however, a first or original source of energy, so, for stationary installations, the energy per pound is not the most important factor. The storage cell is merely a converter of energy; hence, the important property, in so far as energy is concerned, is its efficiency of conversion. This will be discussed later.

RECAPITULATION

1. By *electromotive force* is meant that agent which causes or tends to cause a movement of electricity in a conductor. Although it is called a force or pressure it is not of the same nature as a mechanical force. The unit of electromotive force is the volt.

2. The *volt* is that electromotive force which will cause a current of 1 amp. to flow through a resistance of 1 ohm. The e.m.f. of a lead storage cell, when charged, is about 2 to 2.2 volts.

3. Commercially, an electromotive force is generated in two ways. One method consists in moving conductors wound on iron cores across magnetic fields. This is the principle employed in electric generators and is known as electromagnetic induction. The other method is by chemical action, as in electric cells.

4. The *electromotive force* of an electric cell depends upon the materials of which it is made and upon its temperature.

5. An *electric current* is a continuous transfer of electricity, or, according to modern theory, it is a continuous transfer of electrons under the influence of an electromotive force.

6. An *ammeter* is an instrument for the measurement of electric current in amperes. Direct-current ammeters are usually of the permanent magnet movable coil type. The interaction between the magnetic field of the permanent magnet and the magnetic field produced by the current in the coil produces a deflection which is proportional to the current measured.

7. An *ammeter shunt* is a low resistance resistor which is connected in series with the circuit in which the current is to be measured. The current in the ammeter, which is connected to the terminals of the shunt, is then proportional to the voltage drop across the shunt. As this is proportional to the current, the ammeter reading is proportional to the main current. The ammeter may be calibrated to give the main current directly.

8. An *ampere-hour meter* is an instrument which registers the total quantity of electricity in ampere-hours that has passed through the circuit in a definite interval of time. It is a useful instrument for storage battery work.

9. A *voltmeter* is an instrument for measuring electromotive force. In principle it is the same as the ammeter except that it is graduated to read in volts instead of in amperes.

10. *Electrical resistance* is that property of an electric conductor through the agency of which the energy of the electric current flowing is converted into heat. The unit is the ohm.

11. The *ohm* is the unit of electrical resistance and is defined as the resistance of a column of pure mercury 106.3 cm. long, of uniform cross-section of one square millimeter at the temperature of melting ice.

12. *Ohm's law* gives the relation between the resistance, current, and electromotive force in a circuit. This relation is given by

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

or

$$\text{volts} = \text{amperes} \times \text{ohms}$$

or

$$\text{ohms} = \frac{\text{volts}}{\text{amperes}}.$$

13. By *voltage drop* in a circuit is meant the product of the current in the circuit times the resistance of that portion of the circuit considered. It is measured in volts.

14. The effect of an increase in temperature upon metallic conductors is to increase their resistance. The effect of increase in temperature on carbon and electrolytes is just the opposite.

15. By *power* is meant the time rate of doing work. In direct-current circuits the product of volts by the amperes resulting, is power. The unit is the watt.

16. The *watt* is the unit of power and is equal to the work done in 1 second when 1 ampere is flowing under a pressure of 1 volt. One thousand watts are called a kilowatt. One kilowatt equals 1⅓ horsepower.

17. The practical unit of energy is the *kilowatt-hour*. It represents the amount of work done in one hour when the power is one kilowatt. A kilowatt hour is equal to 1⅓ horsepower hour.

QUESTIONS

1. Is a storage cell a reservoir of electricity or energy? Explain.

2. Explain what is meant by electromotive force.

3. (*a*) What is a volt? (*b*) What is the voltage of a fully charged storage cell?

4. Explain briefly two commercial methods for generating an electromotive force.

5. What is your understanding of the term "electric current?"

6. Distinguish between electric current and electromotive force. Which is the cause and which the effect?

7. What is an ampere?

8. What is an ammeter? Show by a diagram how to connect an ammeter in a circuit.

9. What is an ampere-hour? Is the ampere-hour a unit of current or of quantity?

10. What is an ampere-hour meter?

11. What is a voltmeter? Show by a diagram how a voltmeter should be connected to a circuit.

12. (*a*) What is meant by electrical resistance?

(*b*) What is the approximate resistance of 2,000 ft. of No. 10 wire?

13. Explain the difference between the resistance and the resistivity of a conductor.

14. What effect does a change in temperature have upon the resistance of electrolytes?

15. State Ohm's law.

16. A starting battery whose e.m.f. is 6 volts has a negligible internal resistance. The lamps to which it is connected have a resistance of 2 ohms. What current flows through the lamps?

17. (*a*) Referring to Question 16, what is the voltage drop across the battery?

(*b*) What is the voltage drop across the lamps?

18. A 6-volt starting battery gives a current of 100 amp. on starting. What is the power output?

19. Distinguish between power and work.

20. (*a*) What is the unit of power?

(*b*) What is the unit of work?

21. Is the energy per pound of a storage cell as important as its efficiency? Explain.

22. A central station storage battery supplies current at 220 volts. The current supplied for 1 hour averages 2,000 amperes. What is the output of the battery in kilowatt-hours?

CHAPTER III

CHEMISTRY OF THE STORAGE CELL

28. Physical and Chemical Changes.—Substances may undergo two characteristic changes. When water freezes, and the resulting ice is broken up, or when the filament of an incandescent lamp is heated by an electric current, changes of form, size, or temperature take place, but the essential nature of the substance does not change. Water in the liquid form will not burn, neither will ice. In fact, the nature or composition of water and ice is the same. They differ in physical properties only. Changes which do not alter the composition or essential properties of the substance are called *physical changes.*

Substances are continually undergoing another type of change, as when coal burns, acid corrodes a metal, iron rusts, food is digested, the brown coating on the positive plate of a storage cell turns white, etc. These are all changes which accompany a change in the composition of the substance. Such changes are called *chemical changes.*

29. Chemical Changes.—If a piece of coal be heated to incandescence and then the source of heat be removed, it will be observed that the coal does not return to its original condition as does the filament of an incandescent lamp when it is heated. On the other hand, it continues to glow with increased intensity and the bulk of the charcoal gradually diminishes until nothing but a white ash is left. The coal combines with the oxygen of the air and forms carbon dioxide which escapes into the air. The combination of the oxygen with the carbon liberates or generates heat which maintains the temperature at the combustion level, and this continues until all of the coal, except the ash, is consumed. The matter which composes the coal is not annihilated, it is merely changed in form and chemical composi-

tion; that is, it undergoes a chemical change. Again, if a solution of copper sulphate, blue vitriol, be made and if a current of electricity be passed through the solution, the copper sulphate will likewise undergo a chemical change. In the case of the charcoal, the chemical change is caused by heating until combustion takes place. It then continues of itself with the evolution of heat or energy. In the case of the copper sulphate, the change is produced by the electric current; and if the current stops, the change ceases. In this process energy is absorbed but not liberated.

Chemical changes that are produced by the passage of an electric current are electrochemical changes, and processes involving these are called electrochemical processes. Examples of such processes are electroplating and all electrolytic transformations. The important characteristic of a chemical change is a transformation of the substance into a new one with radically different properties. In many cases heat or energy is evolved while the substance is undergoing a chemical change, and in other cases energy is absorbed.

30. Chemical Reactions.—The changes that take place in a storage cell on charge and discharge are physical, chemical, and electrochemical. The transformation or interaction of materials undergoing a chemical change is called a *chemical reaction*. One of the simplest of chemical reactions takes place when a piece of zinc is placed in dilute sulphuric acid. If this is done, it will be observed that the acid attacks the zinc; and if a sufficient quantity of acid is present, the zinc will ultimately be consumed. After the solution is evaporated, a white powder is the residue. The combination of the acid with the zinc produces a new substance.

In the example given above, the action between the acid and the zinc liberates a considerable amount of energy in the form of heat which ultimately escapes into the air. If, however, a strip of zinc and a carbon rod or copper plate are immersed in the dilute sulphuric acid, Fig. 1, and the two strips are connected by a wire, it will be found

that the wire also becomes warm. Chemical action in this case also takes place between the acid and the zinc, but all of the energy set free is not confined to the solution as in the first case. Some of it is converted into electrical energy which flows along the wire and heats it. In other words, the energy of chemical reaction is converted into electrical energy. Such, in brief, is the chemical action of a simple primary cell.

The chemical reactions in the primary cell proceed of themselves; that is, without the addition of energy. In other words, the electrical energy evolved is a result of the chemical action which takes place within the cell. The chemical products resulting from the reaction in the cell are the same as when zinc is dissolved in acid. There is this difference however, the energy liberated when the zinc is dissolved is dissipated as heat in the cell itself, while in the primary cell the energy is converted into electrical energy which may be conveyed along wires to distant points and there do useful work.

In a storage cell, chemical changes also are the source of the electrical energy, but there is a fundamental difference between the primary cell and the storage cell. When the acid in the primary cell has dissolved the zinc, some of the substance composing the cell has escaped and there is no simple process of converting the residue into the original form. In the case of the storage cell the passage of an electric current through it, in a direction opposite to that in which the current flows when the cell is the source of the current, restores the active material of the cell to its original condition. The storage cell is reversible while the simple cell is not. It is this reversibility of the storage cell that makes it such a useful piece of apparatus. To understand the reversibility, it is necessary to have some notion of the chemical and electrochemical changes that take place in the storage cell. These changes are usually expressed by chemical symbols and equations.

31. Chemical Symbols and Equations.—When expressing the results of chemical reactions, chemists do not use

the ordinary commercial names for the substances that take part, or are agents, in the reaction. The substances are represented by symbols which express their composition. All material substances are either simple or compound. That is, some substances consist of only one kind of matter, which by no known process can be resolved into dissimilar substances. These single substances are elements, and the chemist symbolizes them by single letters, or abbreviations of their names. Thus the element, oxygen, is represented by the letter O, hydrogen by H, sulphur by S, lead by Pb, etc. These symbols, when used in a chemical equation, do not merely represent the substances, but the weights of equal volumes in the gaseous condition as compared with hydrogen.

The substances known as compounds are chemical combinations of the elements. These compounds have entirely different properties from the elements. Thus water which results when hydrogen is burned in an atmosphere of oxygen is chemically represented by the symbol H_2O, which means that two parts by volume of hydrogen have combined with one part by volume of oxygen, and the result is two parts by volume of steam. If the relative weights of the elements are considered, the ratio is 2 parts of hydrogen to 16 of oxygen, or 1 to 8. Expressing the burning of hydrogen in an atmosphere of oxygen by an equation, we write it as follows:

$$2H_2 + O_2 = 2H_2O$$

which shows that the combination of hydrogen and oxygen, two elements, produces a new substance which has properties that differ radically from those of its constituent elements. The weight of the substances that enter into combination is the same as that of the product. Thus the combustion of 1 gram of hydrogen requires 8 grams of oxygen and will produce 9 grams of water, or 1 lb. of hydrogen will combine with 8 lb. of oxygen to form 9 lb. of water.

The electrolyte of a lead storage cell is dilute sulphuric acid. The chemical symbol for sulphuric acid is H_2SO_4

which translated into English means that sulphuric acid is a compound of hydrogen, H, sulphur, S, and oxygen O. The symbol, however, tells more than this. It also shows that the compound consists of two volumes of hydrogen, one of sulphur, and four of oxygen; and if we consider the combining weights, they are 2 of hydrogen, 32 of sulphur, and 64 of oxygen. One pound of sulphuric acid, therefore, consists of $\frac{2}{98} = \frac{1}{49}$ lb. of hydrogen, $\frac{16}{49}$ lb. of sulphur, and $\frac{32}{49}$ lb. of oxygen. All of this is indicated or can be deduced from the symbol H_2SO_4. Chemical symbols are thus an abbreviated or "shorthand" method of expressing certain properties of chemical substances, and the chemical equation is an expression which attempts to show how compounds are formed and what reactions take place when substances undergo chemical changes.

32. Atoms and Molecules.—These terms are often used in explaining chemical reactions and equations, and hence a brief explanation of them is necessary.

Whenever two or more elements are combined to form a chemical compound, the combining weights of these elements always have the same numerical ratio. This is explained on the assumption that matter is granular, or, expressed in another way, the facts seem to indicate that matter may be subdivided until so small a particle is reached that it is no longer divisible by any known chemical means. This particle is the atom. The modern electron theory has modified this conception of the constitution of matter, but chemical formulas are still written in accordance with the older theory.

There are about one hundred different kinds of atoms known; that is, the same as the number of elements. The individual atoms in each element are exactly alike, but the atoms of different elements differ in size and still more in weight. The atom of hydrogen is the lightest and smallest, and the heaviest atom, uranium, is the largest. The complexity of the material universe is due to the different characteristics and properties of the atoms. One of the most characteristic properties of atoms is their

readiness to combine with other atoms. When atoms combine, they do so in regular, definite ways, forming groups known as molecules. The same atoms may be grouped into quite different molecules just as the same bricks may be used for different structures or the same letters may be used to form different words. The letters composing the word may be considered as analogous to atoms and the words to molecules; thus if the chemical notation be applied to words, the word "see" may be written SE_2. Matter whose atoms are of like kind is called an element, and matter whose molecules are composed of different kinds of atoms is called a compound.

In the formulas and equations of the chemical reactions already explained, the single letters represent atoms and the groups represent molecules. Thus the fundamental lead storage cell reaction is written as follows:

$$Pb + PbO_2 + 2H_2SO_4 = 2PbSO_4 + 2H_2O$$

This translated into terms that have just been explained means that one molecule of lead (Pb) plus one molecule of lead peroxide, or lead dioxide (PbO_2), plus two molecules of sulphuric acid ($2H_2SO_4$) combine to form two molecules of lead sulphate ($2PbSO_4$) plus two molecules of water ($2H_2O$). The equation also shows that a lead molecule and a lead atom are the same; a molecule of lead peroxide consists of one atom of lead and two atoms of oxygen; a molecule of sulphuric acid is composed of two atoms of hydrogen, one of sulphur, and four of oxygen, etc.

33. Cell Reactions.—The chemical substances composing a lead-acid storage cell are:

Substance	Symbol	Substance	Symbol
Lead	Pb	Lead peroxide	PbO_2
Hydrogen	H	Lead sulphate	$PbSO_4$
Oxygen	O	Sulphuric acid	H_2SO_4
Sulphur	S	Water	H_2O

No other chemical substances take part in the action of the lead-acid storage cell.

If we start with a cell fully charged, the positive plate is composed of lead peroxide, PbO_2, and the negative plate of pure lead, called sponge lead. That is to say, those parts of the plate which undergo chemical change (the active material) consist of lead peroxide on the positive and sponge lead on the negative. When connection is made to an outside circuit so that a current will flow, both plates undergo chemical changes in somewhat the same way as when a current is taken from a simple cell. In other words, chemical reactions take place between the plates and the electrolyte. At the positive plate the chemical reaction is expressed by the following equation:

$$2PbO_2 + 2H_2SO_4 = 2PbSO_4 + 2H_2O + O_2$$

At the negative plate the reaction is similar and may be expressed by

$$Pb + H_2SO_4 = PbSO_4 + H_2$$

But these two reactions are simultaneous, and accordingly the complete reaction is the sum of the two, which is

$$Pb + PbO_2 + 2H_2SO_4 = 2PbSO_4 + 2H_2O + \text{energy}$$

Discharge $\longrightarrow$ / $\longleftarrow$ Charge

It will be noticed that exactly the same quantities of lead, of hydrogen, of oxygen, and of sulphur are on each side of the equality sign. No material has been destroyed. It has simply been rearranged in a new combination. The above equation means that a plate of lead and a plate of lead peroxide immersed in a solution of sulphuric acid and connected by wires to a circuit so as to permit the flow of an electric current will gradually all be converted into lead sulphate and water and an electric current will flow

in the circuit. The changes, from left to right, indicated above take place of their own accord, and as a result energy is liberated which may be used to do useful work. The changes differ in no essential from those which take place in a simple galvanic cell. If some cheap process of manufacturing sponge lead and lead peroxide were known, and if a lead cell with all the characteristics of a storage cell could be built by merely combining the materials without any charging process whatever, it could be used as a source of electric current. The chemical equation shows that definite and concrete amounts of lead, lead peroxide, and sulphuric acid combine. This combination proceeds of itself exactly in the same way as when sulphuric acid is poured on zinc in a test tube.

If the materials are combined in the following proportions by weight, 207 parts of lead, 239 parts of lead peroxide, and 196 parts of sulphuric acid, the result will be 606 parts of lead sulphate and 36 parts of water, and a definite amount of energy will be set free. If the reaction is perfectly reversible and none of the material escapes or is lost, the material may be restored to its original condition by expending an equal amount of energy upon it. The energy liberated by the chemical reaction in the storage cell is conveyed by wires to places where it is utilized. When the active material has all been converted into lead sulphate, the two plates are alike and no more energy is liberated. The cell is then completely discharged. In practice, the process is not permitted to continue to this extent.

The energy required to restore the active material on the right-hand side of the equation to its original form as shown on the left is supplied by the electric current on charge. Charging a storage cell is thus a process of supplying energy to it in such a manner as to convert the active material into a form that will combine with sulphuric acid of its own accord. On discharge, the electric current in the cell flows from the sponge lead, or negative, plate to the lead peroxide plate. On charge, the electric current in the cell flows from

the peroxide, or positive, plate to the sponge lead, or negative, plate. When the cell is discharged, the active material on both plates is lead sulphate. The formation of lead sulphate is the normal result of the action of a lead storage cell.

34. Variation in Specific Gravity during Charge and Discharge.—The equation for the chemical reactions of a cell shows that during discharge the sulphuric acid in the electrolyte is gradually converted into lead sulphate and water. The lead sulphate is not in solution, and, as the specific gravity of water is unity or ten hundred points, it is readily seen that the specific gravity of the electrolyte becomes lower during discharge. This is a most important point as it gives one of the surest methods of determining the condition of a cell. Conversely, when the cell is being charged, there is a steady conversion of the lead sulphate into lead, lead peroxide, and sulphuric acid with a consequent rise in the specific gravity of the electrolyte. The charge is completed as soon as all of the lead sulphate is converted. This is indicated by a stoppage in the rise of the specific gravity of the electrolyte.

On a preceding page it was pointed out that heat is produced when sulphuric acid is added to water. It is reasonable then to expect a cooling effect when sulphuric acid is removed from the solution, as occurs when the cell is discharging. During discharge there is present a heating effect due to the passage of current through the electrolyte and a cooling effect due to the abstraction of sulphuric acid from the solution. The former effect usually predominates, so there is also a slight heating on discharge.

35. Faraday's Law.—The decomposition of an electrolyte by the passage of an electric current through it was investigated by Faraday who stated the laws governing the decomposition as follows:

1. When electricity is passed through a solution, the mass of the decomposed solution is proportional to the quantity of electricity passed.

2. The mass of any substance liberated by a given quantity of electricity is proportional to the chemical equivalent of the substance.

The first law means that a given current of electricity, flowing for a given time, will always deposit the same mass or weight of a given element from a solution, irrespective of the concentration of the solution that contains the element or of other conditions.

According to the second law, the mass of the substance deposited will depend upon its combining weight, which is called chemical equivalent. Thus, when a solution of copper salt is used as the electrolyte, the mass of copper deposited will depend upon whether a cupric or cuprous salt is used. The chemical symbol for cupric chloride is $CuCl_2$ and for cuprous chloride CuCl. From this it will be seen that the combining weight of copper in the cuprous compound in comparison with the weight of chlorine is twice that in the cupric compound. The combining weight is twice as great, and twice as much copper will be deposited by a given current from a cuprous solution as from a cupric solution. The law also states that when solutions of different compounds are decomposed, the weights of material deposited by a given current are proportional to the combining weights of the materials or elements forming the compounds. Thus, 1 amp. sent through a solution of silver nitrate for an hour will deposit 4.025 grams of silver. The same current sent through a solution of copper sulphate will deposit only 1.184 grams of copper in 1 hr. These laws are the fundamental principles of all electrolytic operations.

36. Electrolysis.—All electrochemical reactions obey Faraday's laws. An extended discussion of the nature of electrolysis does not properly belong to the study of storage cells, but the following definitions and principles are an aid in understanding the literature on the subject. An *electrolytic cell* is a combination of conductors, electrolyte, and container in which electrolysis takes place. The current enters the cell through one conductor and leaves at the

other. These conductors are called *electrodes*. The electrode by which the current enters is called the *anode*. The electrode by which the current leaves the electrolyte is called the *cathode*.

Ions.—The elements of an electrolyte which carry the electricity through the electrolyte are called ions. Ions are not produced by the action of an electric current but are already in the solution. No current passes through a solution unless there is a movement of an equivalent amount of each of two ions, the one toward the anode, called the anion, and the other toward the cathode, called the cation. Ions may be regarded as parts of molecules, each charged with a minute quantity of electricity, either positive or negative. The electrolyte is filled with ions; and, when an e.m.f. is connected to the electrodes, the *cations* with positive charges move toward the cathode and the *anions* with negative charges move toward the anode. This transfer of electricity by means of charged atoms or groups of atoms, called ions, constitutes the electric current through the electrolyte. Since each ion carries a fixed charge it follows at once that the mass of a substance decomposed by the passage of an electric current is directly proportional to the quantity of electricity passed through the solution. This is Faraday's first law.

The electrolyte of the storage cell is composed of the ion hydrogen and the acid radical "SO_4." When a current is passed, the hydrogen ion moves toward the cathode where it gives up its charge, and the sulphion, or acid, radical, moves towards the anode and there gives up its charge. When the current is reversed, the direction of the movement of the ions is reversed. Just as soon as the hydrogen ion has given up its charge at the cathode it becomes ordinary hydrogen which either combines with oxygen to form water, or escapes.

37. The Ampere.—One definition of the unit of current has already been given. The practical definition is, however, based on the electrolytic action of the current in accordance with Faraday's laws. It is as follows:

The ampere is the unvarying electric current which, when passed through a standard solution of silver nitrate, deposits silver at the rate of 0.001118 gram per second. An ampere will thus deposit 4.025 grams of silver per hour. An ampere will also convert in a storage cell 4.46 grams of lead peroxide to lead sulphate in 1 hour.

38. The Coulomb and Ampere-hour.—An electric current is the rate of flow of electricity. Quantity of electricity is the total amount passing a given point in the circuit. The unit of current is the ampere defined above, and the unit quantity is the *coulomb*, which is the quantity of electricity passing a given point in the circuit in one second when one ampere is flowing. If we assume a unit quantity of water to be 1 gal., then the current that gives 1 gal. in 1 sec. would be considered as a unit current.

The unit of quantity for storage battery work is 3,600 coulombs, called the *ampere-hour*. The ampere-hour is evidently the quantity of electricity which passes when 1 amp. flows for 1 hour. An ampere-hour will convert 4.46 grams of lead peroxide to lead sulphate.

The mass of any metal deposited by one coulomb of electricity is called the *electrochemical equivalent*.

39. Equivalent Weights.—In discussing chemical reactions and formulas it was shown that the elements combining to form a new compound do so in definite relations. The symbol for nitric acid is HNO_3. If we dissolve silver in nitric acid, the reaction is expressed by the following formula:

$$2HNO_3 + Ag_2 = 2AgNO_3 + H_2$$

If hydrogen is taken as the standard of mass and the mass of the silver that has replaced the hydrogen in the nitric acid is compared with it, it will be found that 107.88 times as much silver was consumed as hydrogen was liberated. The relative combining weights of silver and hydrogen are, therefore, 107.88 to 1. If enough silver be combined with nitric acid to liberate one gram of hydrogen, it is evident that the mass of silver necessary will be 107.88

grams. The electrochemical equivalent of silver is 0.001118 gram; that is, one coulomb of electricity will deposit 0.001118 gram. And to deposit 107.88 grams will require 107.88 divided by 0.001118 which is 96,540 coulombs. This same number of coulombs will deposit the equivalent weight of any other metal which can be electrolyzed in the same way.

This 96,540 coulombs is the electro-chemist's unit quantity of electricity. In Table IV, column 1, is given the number of grams of substance which is liberated by the passage of 96,540 coulombs.

TABLE IV.—WEIGHT OF METAL LIBERATED BY UNIT QUANTITY OF ELECTRICITY

	1 Equivalent weight, grams	2 Output per coulomb, grams $\times 10^3$	3 Output per ampere-hour, grams
Copper	31.75	0.329	1.1837
Hydrogen	1.0	0.01036	0.03729
Iron	28.0	0.290	1.0441
Lead	103.5	1.072	3.8595
Nickel	29.25	0.303	1.0907
Oxygen	8.0	0.083	0.2983
Silver	107.88	1.118	4.0273
Zinc	32.5	0.337	1.2119

To convert grams into pounds avoirdupois divide by 453.6.

40. Applications of Faraday's Laws. 1. When a current is taken from a primary cell, such as the Daniell or the dry cell, zinc is dissolved in accordance with Faraday's law. From the table given above if one ampere is taken from the cell for one hour, 1.21 grams of zinc are dissolved. In other words, it requires 1.21 grams of zinc per ampere-hour output of the cell. Since there are 453.6 grams in 1 lb., the ampere-hour output per pound will be 453.6 divided by 1.21 which is equal to 374 ampere-hours. It makes no difference what type of cell is used; if zinc is

consumed in such a cell, no more than 374 ampere-hours per pound can be obtained. If the process be reversed and zinc be deposited in an electrolytic cell by an electric current, it will require 374 ampere-hours to deposit 1 lb.

2. In the normal action of a Daniell cell copper is deposited on the cathode; and if 1 lb. of zinc goes into solution, there will be deposited $\frac{31.75}{32.5}$ lb. = 0.978 lb. of copper.

Practically all copper is now refined by passing an electric current from an electrode of crude copper to another electrode in a solution of copper sulphate. The crude copper enters the solution under the influence of the electric current and is deposited on the other electrode in a pure state. In order to refine 1 lb. of copper it is necessary to pass 384 ampere-hours through the solution. This is obtained by dividing 453.6, number of grams in 1 lb., by 1.184, number of grams deposited by 1 ampere-hour.

3. Referring to the fundamental chemical equation of the storage cell it is seen that lead sulphate is decomposed and converted into sponge lead at the negative plate and lead peroxide at the positive plate. In addition to the conversion of lead sulphate into sponge lead and lead peroxide some of the water of the electrolyte is decomposed, liberating hydrogen which escapes. The number of grams of water which is decomposed by 1 ampere-hour is 0.3356, and 1,350 ampere-hours are necessary to decompose 1 lb. of water.

4. The equivalent weights of sponge lead, lead peroxide, and sulphuric acid in the storage cell are as follows:

	Equivalent Weight, Grams	Output per Ampere-hour, Grams
Lead sponge	103.5	3.86
Lead peroxide	119.5	4.45
Sulphuric acid	98.0	3.60
Total	321.0	11.91

Assuming 100 per cent efficiency, the passage of 1 ampere-hour of electricity through the cell forms 3.86 grams of sponge lead, 4.45 grams of lead peroxide, and 3.6 grams of sulphuric acid, or a total of 11.91 grams of the active material of the cell. Conversely, if 1 ampere-hour is taken from the cell, 11.91 grams of the material are converted into lead sulphate and water.

5. During the discharge of a lead storage cell the equivalent weight of the lead sulphate formed is 303 grams, and the equivalent weight of the water formed in the solution is 18 grams; 321 grams of material are converted into lead sulphate and water by the passage of 96,540 coulombs of electricity. It is seen that exactly the same amount of material is used up or formed during discharge as during charge, which must be so if the cell is completely reversible.

41. Voltage of a Lead Storage Cell.—The electromotive force of any cell depends upon the material of which the cell is made, and not upon the size or number of plates it contains. The e.m.f. of a small dry cell has the same value as the e.m.f. of a large cell. Likewise, the e.m.f. of a small automobile storage cell is the same as that of a large power cell. The voltage of a fully charged storage cell is between 2 and 2.2 volts; on charge it may rise to 2.5 volts or higher. The open circuit voltage also depends upon the concentration of the acid in the electrolyte which is the same as saying that it varies with the specific gravity of the electrolyte. Experiments show that for all acid concentrations used in practice, the voltage of the cell increases at a uniform rate with the concentration.

If C represents the per cent of the sulphuric acid, the e.m.f. at any concentration may be calculated approximately by the following equation:

$$\text{E.m.f.} = 1.9 + (C - 10) \times 0.081 \text{ volts.}$$

EXAMPLE

What is the e.m.f. of a fully charged storage cell whose electrolyte consists of 60 per cent of sulphuric acid?

SOLUTION

$$\begin{aligned}\text{E.m.f.} &= 1.9 + (C - 10) \times 0.081.\\ &= 1.9 + (60 - 10) \times 0.081.\\ &= 1.9 + 50 \times 0.081.\\ &= 1.9 + 0.405.\\ &= 2.305 \text{ volts.}\end{aligned}$$

The above facts seem to indicate that it would be good practice to make the electrolyte highly concentrated. This would be correct were the voltage of the cell the only factor to be considered. The electrolyte is seldom made of a higher density than 1,300 (39.65 per cent H_2SO_4) because it has been found that destructive local action takes place above that point. For stationary cells, it is seldom higher than 1,220.

RECAPITULATION

1. By physical change is meant a change in the size, shape, form, or state of a substance without any alteration in composition.

2. A chemical change is one in which the composition and essential properties of the substance are changed.

3. An electrochemical change is a chemical change produced in a substance by electrical means.

4. A chemical reaction is the transformation or interaction of substances undergoing a chemical change.

5. Chemical symbols are letters or combinations of letters which represent the composition of substances. The symbols for elements are usually the first letters, or abbreviations, of their names.

6. A chemical equation is an expression involving chemical symbols in mathematical form which attempts to express what takes place in a chemical reaction.

7. An atom, according to the atomic theory, is the smallest indivisible particle of matter.

8. A molecule is the smallest particle of a compound. It consists of a combination of atoms.

9. Chemical reactions take place with an absorption or liberation of energy. On charge, the reactions in a storage cell absorb energy; on discharge, the reactions liberate energy. The storage cell is thus a converter of energy.

10. The electrolyte in a storage cell is an active agent in the reactions and accordingly undergoes changes in density. On charge, its density increases and on discharge it decreases.

11. Faraday's laws are a definite and concrete statement of the principles of electrolysis. They are:

1. When electricity is passed through an electrolyte, the mass of the solution decomposed is proportional to the quantity of electricity passed.

2. The mass of any substance liberated by a given quantity of electricity is proportional to the chemical equation of the substance.

12. An electrode is the solid conductor by which an electric current is conveyed into or out of an electrolytic cell.

13. The anode is the electrode by which current enters the cell.

14. The cathode is the electrode by which current leaves the cell.

15. Ions are electrically charged atoms or groups of atoms in an electrolytic cell.

16. The ampere is the unvarying electric current which, when passed through a standard solution of silver nitrate, deposits silver at the rate of 0.001118 gram per second.

17. A coulomb is the quantity of electricity that will deposit 0.001118 gram of silver from a standard solution of silver nitrate.

18. The *ampere-hour* is equal to 3,600 coulombs.

19. The electrochemical equivalent of an element is the mass of the element deposited by one coulomb.

20. The voltage of a lead storage cell varies with the concentration of the electrolyte. The normal open circuit voltage of a fully charged cell is from 2.05 to 2.2 volts.

QUESTIONS

1. Explain and give examples of physical changes not mentioned in the text.

2. Explain and give examples of chemical changes not mentioned in the text.

3. Give the chemical symbol for lead, lead sulphate, lead peroxide, sulphuric acid.

4. Name the substances on both sides of the following equation:

$$Pb + PbO_2 + 2H_2SO_4 = 2PbSO_4 + 2H_2O.$$

5. What changes take place on the positive plate of a lead cell on charge?

6. What changes take place on the positive plate of a lead cell on discharge?

7. What changes take place on the negative plate of a lead cell on charge? Express these by a chemical equation.

8. What changes take place on the negative plate on discharge? Express these by a chemical equation.

9. (*a*) Is electricity stored in a storage cell?

(*b*) What takes place when a current of electricity is passed through the cell?

10. What changes take place in the specific gravity of the electrolyte on charge and discharge? Explain the cause.

11. State Faraday's two laws.

12. When a storage cell is charging, is the peroxide plate the anode or cathode? Explain.

13. What is meant by ion? What are the ions in a lead storage cell? Is a charged hydrogen atom an anion or a cation?

14. Give the practical definition of the ampere.

15. A current of 10 amp. is drawn from a lead storage cell for 5 hours. How much lead peroxide is converted into lead sulphate?

16. A lead cell is charged for 10 hours by a current of 8 amp. How much lead sulphate is converted into lead peroxide?

17. Upon what factors does the voltage of a storage cell depend?

18. The voltage temperature coefficient of a lead acid cell is approximately .00033 volts per degree centigrade. A fully charged cell has a voltage of 2.02 volts at 20 degrees centigrade. What is its voltage at 40 degrees centigrade?

19. Why not use highly concentrated electrolyte in a lead cell?

20. What is the maximum density of electrolyte for stationary cells?

CHAPTER IV

NICKEL-IRON-ALKALINE CELL

42. General.—It was pointed out in connection with the lead-acid cell that its usefulness depended upon its reversibility. Any combination of materials that will undergo a reversible chemical change when an electric current is passed through it may be used as a storage cell. Its practicability will, however, depend upon many factors; namely, cost of material, cost of manufacture, efficiency of conversion, permanency, etc. Only two combinations thus far meet the necessary conditions. These are the lead-acid-lead combination and nickel-alkali-iron combination, known as the Edison storage cell.

43. Elements of the Edison Storage Cell.—The elements of the Edison storage cell are a container of nickel-plated steel, a positive electrode consisting of a steel grid with a number of tubes containing the active material, a negative electrode or plate also of steel with an active material of iron oxide, and an electrolyte of potassium hydroxide.

44. The Container.—The containing vessel is a rectangular shaped jar of nickel-plated steel, Fig. 21, welded at the seams by an oxyacetylene flame or other autogenous process. The walls of the container are corrugated so as to give maximum strength with minimum weight. The bottom and cover are of the same quality nickel-plated sheet steel. The terminal posts are sealed in the cover and insulated by rubber gaskets. Mounted on the cover and situated between the two terminal openings are the gas vent and filler cap combined. These consist of a seat, a hemispherical valve, and a cover which is held open or shut by a spring. The valve is arranged to permit the escape of the

gases under pressure and to prevent the entrance of air and other impurities.

FIG. 21.—Edison cell container.

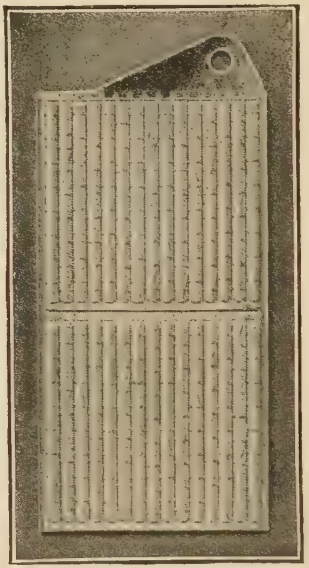


FIG. 22.—Positive plate of Edison cell.

45. The Positive Plate of the Edison Cell.—The positive plate consists of a steel grid or frame, Fig. 22, in which a number of tubes, Fig. 23, containing the active material,

FIG. 23.—Tube of Edison positive plate.

are mounted. The active material is nickel hydrate, a green colored compound which is packed into the tubes under heavy pressure. This nickel hydrate is packed in layers alternating with very thin layers of pure nickel flakes. The metallic layers of nickel act as conductors

of the electric current to all parts of the active material in the tubes. The passage of the electric current during charge and discharge alternately oxidizes and reduces the nickel hydrate. The tubes are made of perforated nickel-plated steel and are 4½ in. in length and ¼ in. in diameter. In order that they may withstand heavy pressure applied to the active material during the process of packing, they are surrounded at intervals of ½ in. with steel rings.

FIG. 24.—Negative plate of Edison cell.

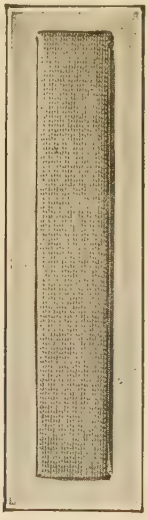


FIG. 25.—Steel pocket of Edison negative plate.

46. The Negative Plate of the Edison Cell.—The negative plate, Fig. 24, consists of a number of rectangular, steel pockets, Fig. 25, filled with iron oxide commonly called black iron rust. The pockets are made of perforated steel ribbon. The perforations are so small that there are 560 of them to each square inch. These pockets or boxes are perforated in order that the electrolyte may have access to the iron oxide within. They are ½ in. wide, 3 in. long, and ⅛ in. thick. A special machine is used to press the

halves together and crimp the joints. Twenty-four of these pockets are assembled in each plate in one type of cell.

47. The Plate Groups.—The positive and negative plates are mounted on steel rods which have a piece projecting through the top of the cell for the terminal connections, Fig. 26. These groups of plates are sandwiched or dovetailed together in a manner similar to that used in the lead-acid cells, Fig. 27. One less positive than negative is used, and rubber insulation keeps the plates separated so as to prevent short-circuits. A complete cell with side cut away is shown in Fig. 28. A group of Edison cells connected in series and mounted in a portable case is shown in Fig. 29.

FIG. 26.—An element of the Edison cell.

48. The Electrolyte.—A solution of potassium hydroxide, of specific gravity 1,200, is used for the electrolyte. This electrolyte has no effect on iron or steel. Consequently, the containing vessel or jar is made of steel. This is one very important advantage over the lead cell. On the other hand, the solution of potassium hydroxide will absorb carbon dioxide gas from the air forming potassium carbon-

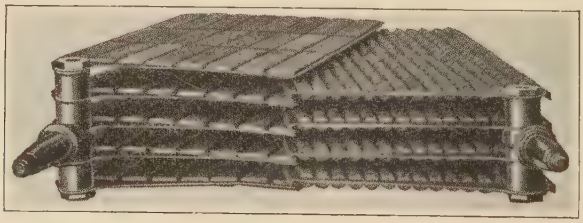


FIG. 27.—Assembly of negative and positive plates.

ate, a hard white substance of no value as an electrolyte. In order to prevent or limit this absorption of carbon dioxide, air is not allowed to enter the cell except in filling. The air

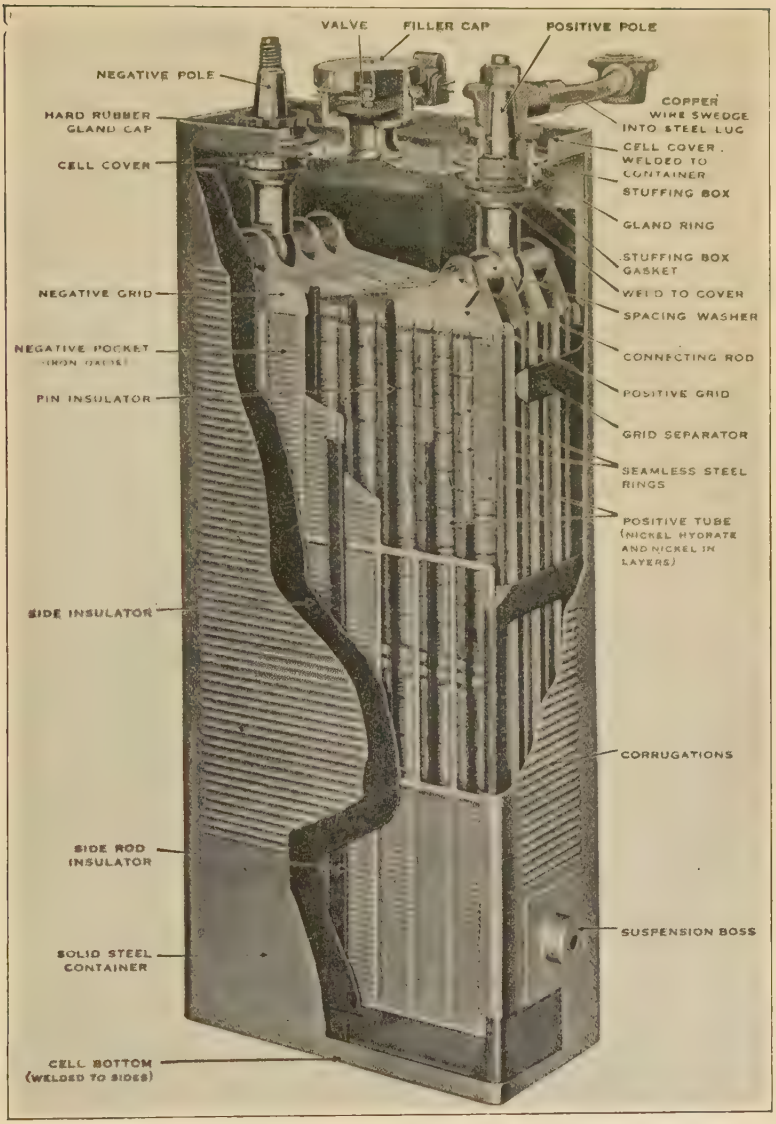


FIG. 28.—An Edison cell.

is excluded by the specially designed filler cap explained under container. The cap serves as a check valve which may be lifted to permit the addition of water and the escape of gas formed in charging. This gas as it rises through the solution, in either the lead cell or the Edison cell, carries with it some of the solution. In the case of the lead cell some of the acid is carried into the air and is the cause of the irritating atmosphere in a battery room. In the

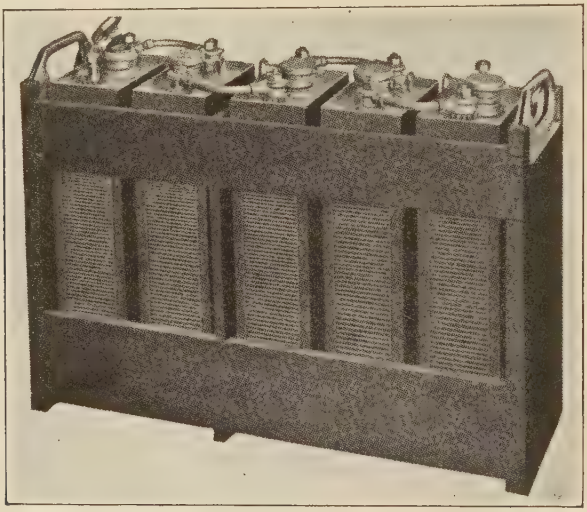


FIG. 29.—A group of portable Edison cells.

Edison cell some of the solution is carried off by the gas, but because of the fact that the gas cap is arranged to open under pressure many of the bubbles burst and the potassium hydroxide drains back into the solution from the inside of the cover of the cell.

It is an interesting fact that the tendency of the electrolyte (potassium hydroxide) to absorb carbon dioxide from the air has been put forth as a possible advantage in case the cells are employed in submarines. The air in the submerged submarine becomes vitiated with carbon dioxide gas, and it has been suggested that the battery solution might be employed to absorb it and assist in maintaining the purity

of the air. The nickel-iron-alkaline cells are, for other reasons, not suitable for submarine use.

49. Voltage of the Edison Cell.—After the cells are assembled they are charged and discharged four times and are then said to be "formed." Figure 30 shows the variation in voltage of an Edison cell during charge and discharge. It will be observed that these curves have somewhat the same characteristics as the charge and discharge curves of the lead cells. The flexures, however, are not so abrupt

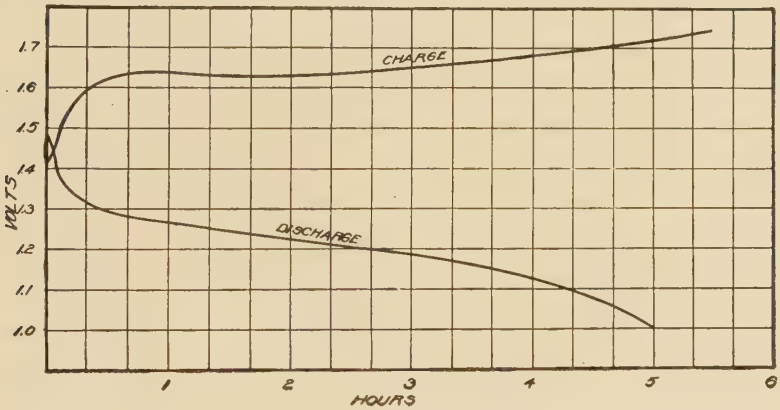


FIG. 30.—Voltage curves of Edison cell.

which is perhaps due to more rapid diffusion. The voltage required for charging is from 1.75 to 1.85 volts per cell, and the voltage during discharge at a normal rate is 1.2 volts per cell. In view of the fact that the voltage of the Edison cell is so much lower than that of the lead cell, a greater number of cells are required to make up a battery for the same voltage.

50. The Chemical Reactions of the Edison Cell.[1]—"The fundamental principle of the Edison Storage Battery is the oxidation and reduction of metals in an electrolyte which neither combines with nor dissolves either the metals or their oxides. Also, an electrolyte which, notwithstanding

[1] "The Edison Alkaline Storage Battery," written by the Technical Staff of the Edison Storage Battery Company.

its decomposition by the action of the battery, is immediately reformed in equal quantity. It is, therefore, a practically constant element without change of density or conductivity over long periods of time. Therefore, only a small quantity of such electrolyte is necessary, permitting a very close proximity of the plates. Furthermore, it is unnecessary to take hydrometer readings until about three hundred cycles of charge and discharge have been made; this is simply to determine when it is necessary to empty out the old solution and put in new. The active materials of the electrodes being insoluble in the electrolyte, no chemical deterioration takes place therefrom.

"The chemical reactions in charging the Edison Storage Battery are (1) the oxidation from a lower to a higher oxide of nickel in the positive plate, and (2) the reduction from ferrous oxide to metallic iron in the negative plate. The oxidation and reduction are performed by the oxygen and hydrogen set free at the respective poles by the electrolytic decomposition of water during the charge. The charging of the positive plate is, therefore, simply a process of increasing the proportion of oxygen to nickel. The proportions of nickel to oxygen in definite oxides of nickel are as follows:

	Atomic proportions		By weight	
	Ni	O	Ni	O
NiO	1	1.0	1	0.273
Ni_3O_4	1	1.33	1	0.364
Ni_2O_3	1	1.5	1	0.409
NiO_2	1	2.0	1	0.545

"The relative amounts of oxygen necessary to oxidize nickelous oxide, or NiO, which is the oxide corresponding

to the green nickel hydrate used in making the battery, to the various oxides are given in the three reactions:

$$(1)\ 6NiO + 2O = 2Ni_3O_4$$
$$(2)\ 6NiO + 3O = 3Ni_2O_3$$
$$(3)\ 6NiO + 6O = 6NiO_2$$

"The NiO_2 is capable of reacting with NiO according to the reaction $NiO_2 + NiO = Ni_2O_3$. Ni_3O_4 is considered as a combination of $NiO + Ni_2O_3 = Ni_3O_4$.

"From a chemical standpoint a charged condition of the cell would, therefore, be represented in the positive plate by an atomic ratio of nickel to oxygen of at least 1:1.5 (or Ni_2O_3), depending on the charge. A discharged condition would be represented by a ratio of 1:1.33 (Ni_3O_4) or lower, depending on the discharge.

"The discharge of the cell is simply the reversal of the above reactions, the hydrogen reducing the higher oxides of nickel to lower oxides and the oxygen oxidizing the iron to ferrous oxide."

51. Classes or Types of Edison Cells.—One type or class of cell is differentiated from another by the number, size, and shape of plates, quantity of active material, etc. These different characteristics are designated by letters and numerals. Cells bearing the same letter, as A4 and A12, or G6 and G9 are made up of the same kind of plates and differ only in the number of plates. The numeral indicates the number of positive plates; that is, the A4 cell has four positive plates, the A12 has twelve positive plates, etc. In every case the negative plates exceed in number the positive plates by one; thus the A4 cell has five negative plates or a total of nine plates. Exceptions to this rule exist in the case of the L, M, and W cells in which cases the numerals indicate the number of positive tubes per cell. When the letter H (meaning high) is affixed to the regular designation of a cell as A8H, it indicates that the cells are taller than regular cells, allowing for a greater height of electrolyte above the tops of the plates. The letter X used in the same manner indicates an intermediate height.

TABLE V.—GENERAL DATA AND TRAY DIMENSIONS OF EDISON STORAGE BATTERIES (¼-IN. POSITIVE TUBES)

Type (Letters denote size of plates-..... Figures number of positive plates).....	B1H[1]	B2	B4	B6	A3	A4	A5	A6	A8	A10	A12	A8H[1]
Rated capacity, ampere-hours.....	18.75	37.5	75.0	112.5	112.5	150.0	187.5	225.0	300.0	375.0	450.0	300.0
Discharge rate (8-hours) amperes.....	2.25	4.75	9.5	14.0	14.0	18.5	23.5	28.0	37.5	47.0	56.5	37.5
Discharge rate (5-hours) amperes.....	3.75	7.5	15.0	22.5	22.5	30.0	37.5	45.0	60.0	75.0	90.0	60.0
Average discharge voltage (8 hours).....	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Average discharge voltage (5 hours).....	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Normal charge rate (7 hours).....	3.75	7.5	15.0	22.5	22.5	30.0	37.5	45.0	60.0	75.0	90.0	60.0
Weight of cell, complete, pounds.....	4.9	4.7	7.5	10.8	11.1	13.9	16.7	19.4	27.2	33.3	41.3	30.7
Weight per cell, in trays, pounds.....	5.7	5.4	8.3	11.7	12.4	15.3	18.1	20.9	29.5	36.2	44.8	33.2
Amount renewal solution per cell, pounds.....	2.0	1.0	1.7	2.5	2.3	2.9	3.6	4.3	5.8	8.2	9.7	8.7
Over-all Tray Dimensions, in Inches												
Width of standard tray.....	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	6⅛	7¾	9	6⅛
[2] Height over-all (filler cap closed).....	11⅜	9⅝	9⅝	9⅝	14⅜	14⅜	14⅜	14⅜	14¾	14¾	15½	17½
[2] Height over-all (filler cap open).....	12⅜	10⅝	10⅝	10⅞	16	16	16	16	16⅜	16⅜	17	19⅛
Length of trays: 1-cell tray.....	3⅛	3⅛	4¼	5⅜	4⅛	4⅝	5¼	5¾	7¼	7½	7½	7¼
2-cell tray.....	5	5	7⅜	9⅝	6¾	7¾	9	10	12⅞	13½	13½	12⅞
3-cell tray.....	6⅞	6⅞	10½	13⅞	9⅜	10⅞	12¾	14¼	18⅜	19½	19½	18⅜
4-cell tray.....	8⅞	8⅞	13⅝	18⅛	12⅜	14	16⅜	18½	24⅛	25⅞	25⅞	24⅛
5-cell tray.....	10¾	10¾	16¾	22⅜	15	17⅛	20	22¾	29¾	32¼	32¼	29¾
6-cell tray.....	12¾	12¾	19⅞	26⅝	17⅝	20¼	23⅝	27¾	36	....	....	36
7-cell tray.....	14⅝	14⅝	23	31¼	20⅝	23¼	28½	32	41⅝	....	....	41⅝
8-cell tray.....	16½	16½	26	35⅝	23¼	27¼	32¼	36¼	47⅛	....	....	47⅛
9-cell tray.....	18½	18½	29¾	39⅞	25⅞	30⅜	36	41⅛	53⅝	....	....	53⅝
10-cell tray.....	20⅜	20⅜	32⅞	44⅛	28⅞	33¼	40⅛	45⅛				
11-cell tray.....	22¼	22¼	36	....	31½	36⅜	43⅞					
12-cell tray.....	24⅜	24⅜	39	....	34⅛	40⅛						

[1] The H type has an extra high container allowing for an excess of electrolyte (about 50 or 60 per cent) and permitting longer intervals between "filling." All above types can be furnished with the extra high container if desired. They are designated respectively as B2H, B4H, etc., and have the same electrical characteristics as B2, B4, etc. The difference in height is about 2¾ in. on the type A and 1¾ in. on the type B—the other dimensions remain identical.

[2] Over-all heights are given for bottomless trays. Add ¾ in. to height and ¼ in. to length for trays with bottoms.

The A type cells are standard for commercial electric vehicles, such as industrial trucks and tractors, locomotives, etc. High cells of this type are used for train lighting, house lighting, and similar service where discharge rates are below normal. The intermediate or X type cells are used for storage battery railway cars. The type A plate has two rows of fifteen positive tubes each, or thirty tubes per plate. Each tube is $\frac{1}{4}$ in. in diameter. The cells have a rating of 37.5 ampere-hours capacity per positive plate when charged and discharged at the normal rate of 7.5 amp. Each negative plate of the type A cell contains twenty-four pockets in three rows of eight pockets each.

The B type cells are used for ignition and lighting of gasoline automobiles and yachts.

The plates of the G type cells have the same surface area as the A type plates, but the tubes are only $\frac{3}{16}$ in. in diameter. More plates may thus be put in the same sized container. This increase in the number of plates permits a higher discharge rate. Each positive plate of the G type cell has two rows of twenty tubes each, or forty tubes in all. The negative plates contain twenty-four pockets each. These pockets have smooth surfaces and are somewhat thinner than the pockets of the A plates. The G type cell is used for light electric vehicles.

The J type cells are used in special classes of service requiring small cells and high discharge rates.

The L type cells are used for aircraft wireless, electric hand lamps, etc.

The M type cells are used for electric hand lamps, motor cycle ignition and lighting, multiple unit control, time clocks, fire alarm systems, etc.

The W type cells are used principally for wireless telegraph.

General data of the more common types are given in Table V.

52. Permanence of the Edison Alkaline Storage Battery. The mechanical construction of the Edison cell coupled with the stability of the combination of nickel hydrate

and iron oxide together with the alkaline solution, account for the remarkably long life of the Edison cell. Among its chief useful characteristics may be listed the following: The chemical reaction appears to be completely reversible, the cell may be left standing idle either charged or discharged for months at a time without injury; severe vibration does not seriously affect the battery; its gases are not noxious or corrosive; it will withstand all ordinary mechanical or electrical mistreatment; its active material does not shed and the cells need not be dismantled to clean out sediment; and the plates do not warp or buckle with excessive rates of current. The owner of one of these batteries should be careful in its use, but occasional accidents such as short-circuits, overcharges, charging in the reverse direction, etc. appear to have no effect upon its life.

RECAPITULATION

1. The Edison storage cell consists of a container of nickel-plated steel, a positive electrode of a steel grid containing an active material of nickel hydrate, a negative electrode also of steel containing iron oxide for the active material, and an electrolyte of potassium hydroxide.

2. The voltage of the Edison storage cell on charge ranges from 1.75 to 1.85 volts; when discharged at the normal rate, the voltage is about 1.2 volts per cell.

3. The electrochemical reaction in the Edison cell is, from a theoretical viewpoint, completely reversible. The chemical changes taking place on charge are an increase in the oxygen content of the positive plate, and a decrease in the oxygen content of the iron oxide of the negative plate. The reaction may be looked upon as a transfer of oxygen from the negative to the positive active material through the agency of the electrolytes. The electrolyte undergoes no permanent change.

4. The trade designation of different classes of Edison cells is based on the size and number of plates and the quantity of active material. The distinction is made by letters and numerals.

5. Because of the fact that the chemical reaction of the Edison cell is completely reversible, the battery has no definite life, its usefulness being limited, theoretically, only by mechanical destruction.

QUESTIONS

1. (*a*) Of what material is the container of the Edison cell made? (*b*) What is the electrolyte of the Edison cell?

2. (*a*) Describe the positive electrode or plate of the Edison cell.

(*b*) What is the active material?

(*c*) What changes take place in the active material on charge?

3. (*a*) Describe the negative electrode or plate of the Edison storage cell.

(*b*) What is the active material?

(*c*) What changes take place in the active material on charge and discharge?

4. (*a*) Does the electrolyte undergo any permanent change on charge and discharge?

(*b*) Does this agree with the theory of electrolysis?

5. Will a hydrometer give any indication of the charged condition of the Edison cell? Why?

6. May air be safely admitted to the electrolyte in the Edison cell? Why?

7. How are the negative and positive plates kept from coming into contact?

8. What is the normal voltage of the Edison cell? May it be discharged safely to zero voltage?

9. What information is conveyed by the designation G9 for a class of Edison cells?

10. (*a*) What is meant by normal charging rate?

(*b*) What is the normal period of charge for the Edison cell?

11. What effect will a too low charge have upon the voltage curve of the cell?

12. Does too high a charging rate have any deleterious effect upon the cell?

CHAPTER V

GENERAL CHARACTERISTICS OF STORAGE CELLS

53. General.—All storage cells have certain general characteristics with which the user or attendant should be familiar to secure from them efficient service and long life. The more common characteristics are discussed in this chapter.

54. Charge and Discharge Rate.—By rate is meant the quantity of anything measured per unit of something else. Thus a passenger rate on a railroad is 3.6 cents per mile, and a freight rate is a certain amount of money per 100 lb. of the commodity, etc.

As explained under chemical reactions of the storage cell, the amount or quantity of active material converted is exactly proportional to the quantity of electricity that is passed through the cell. Hence, it follows that it requires a definite number of ampere-hours to charge a cell, the exact amount varying with the capacity of the cell. The rate at which the cell is charged depends upon the time rate at which the electricity is passed through it. Thus, if it requires 100 ampere-hours to charge a cell, and these 100 ampere-hours are delivered in 10 hours, the rate of charge is 10 ampere-hours per hour. But 10 ampere-hours per hour is 10 amp. if the current is uniform; hence, 10 amp. may be called the charging rate. A charge or discharge rate is the uniform electric current flowing into or out of the cell.

The best, or so-called normal, rate of charge and discharge is determined by considerations of the energy loss within the cell and the resultant heating, of the time required for a complete charge or discharge, and of output. The energy loss due to internal resistance is proportional

to the square of the current. Since this loss is converted into heat, if the current is too high, heat within the cell may be generated more rapidly than it is dissipated.

On the basis of these considerations a greater percentage of the energy input is obtained on discharge if the cell voltage is not reduced to zero. A lead-acid cell is considered discharged when the electrolyte has fallen a specified number of points. The actual specific gravity limit varies

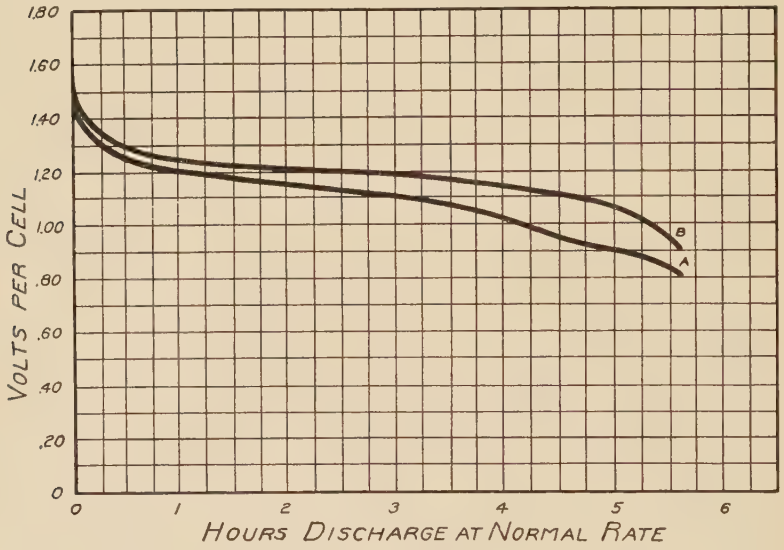


FIG. 31.—Discharge voltage curves of nickel-iron cells at different rates of charge.

with the type of cell and the maximum specific gravity employed. In general the limit of specific gravity is 1,100 to 1,150 and of the voltage about 1.7 volts. Since the specific gravity of the nickel-iron-alkaline cell does not change with the energy content of the cell, its state of discharge is determined by its final voltage. When this falls to 0.9 volt, it is considered discharged.

The normal discharge rate is that current which will discharge it within a specified time. This time varies with the type of cell and the maker. For stationary cells this time has been arbitrarily fixed at 8 hours. For portable and vehicle batteries the time limit may be 5 or 6 hours.

The normal charging rate for the nickel-iron cell is that current which will fully charge the cell in 4¾ hours or 7 hours depending upon the class of cell. It is judged that the efficiency and ampere-hour output are in the best relation for average practice when the cell is charged and discharged at normal rates.

The charging current and, consequently, the duration of charge may be varied through a wide range without seriously damaging the cell. Two facts should, however, be kept in mind; namely, a too low charging rate will not completely reduce the iron oxide, and the resulting discharge voltage curve will be below that of a cell charged at the normal rate. This is shown in Fig. 31, in which curve *A* shows the discharge voltage of a 420 ampere-hour cell charged at 20 amp., and *B* the voltage of the same cell when charged at the normal rate of 60 amp. A too high charging current will overheat the cell; and, if the cell is continuously charged and discharged at a too high rate, the high temperature will be injurious, shortening the useful life of the cell.

55. Internal Resistance.—By internal resistance of a cell is meant that factor which is effective in converting some of the energy of the cell into heat. Or, more concretely, it is that factor by which the square of the current flowing through the cell must be multiplied to give the energy converted into heat. This quantity varies both with the type of cell and the rate of charge or discharge. The common method of measuring the internal resistance is to measure its voltage at two different current rates of discharge and then to divide the difference in the two voltage readings by the difference in the currents.

The resistance of a storage cell depends upon several factors such as the specific gravity of the electrolyte, the resistance of the active material, the closeness of its contact with the supporting grid, the resistance of the grids and terminals, and the plate surface exposed to the electrolyte. The internal resistance of a storage cell increases during discharge and decreases during charge.

This variation of resistance is shown for the lead cell by the curve, Fig. 32, and for the nickel-iron cell by Fig. 33. Both of these figures show that the resistance of both kinds of cells increases rapidly toward the end of the discharge period.

The change in the resistance at the plates of the lead-acid cell is mainly due to the formation of lead sulphate which has a much higher resistance than the peroxide or sponge lead. During discharge the outer layers of the lead and peroxide are first converted into lead sulphate. If the

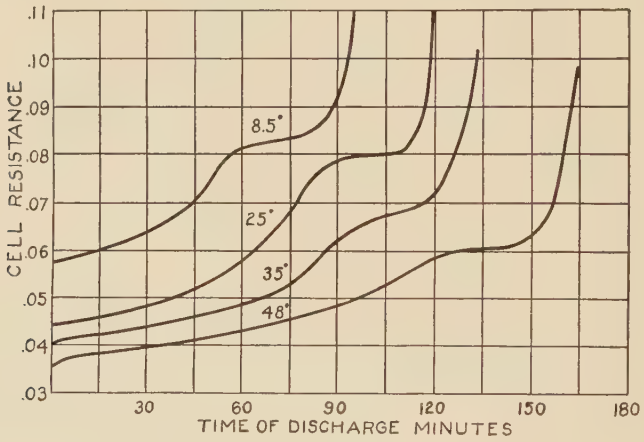


Fig. 32.—Changes in cell resistance with temperature.

cell stands in a discharged condition for a comparatively long time, this layer of sulphate becomes hard and dense and the internal resistance of the cell rises to a relatively high value.

Any current which passes into or out of the cell must pass through the sheets of electrolyte between the positive and negative plates. The cell resistance is made up of three other factors in addition to the resistance of these sheets of acid. One of these factors is the resistance of the supporting grid; a second is the resistance of the active material; and a third is the resistance of the electrolyte in the pores of the active material. The last is the most variable factor in the total cell resistance. The chemical

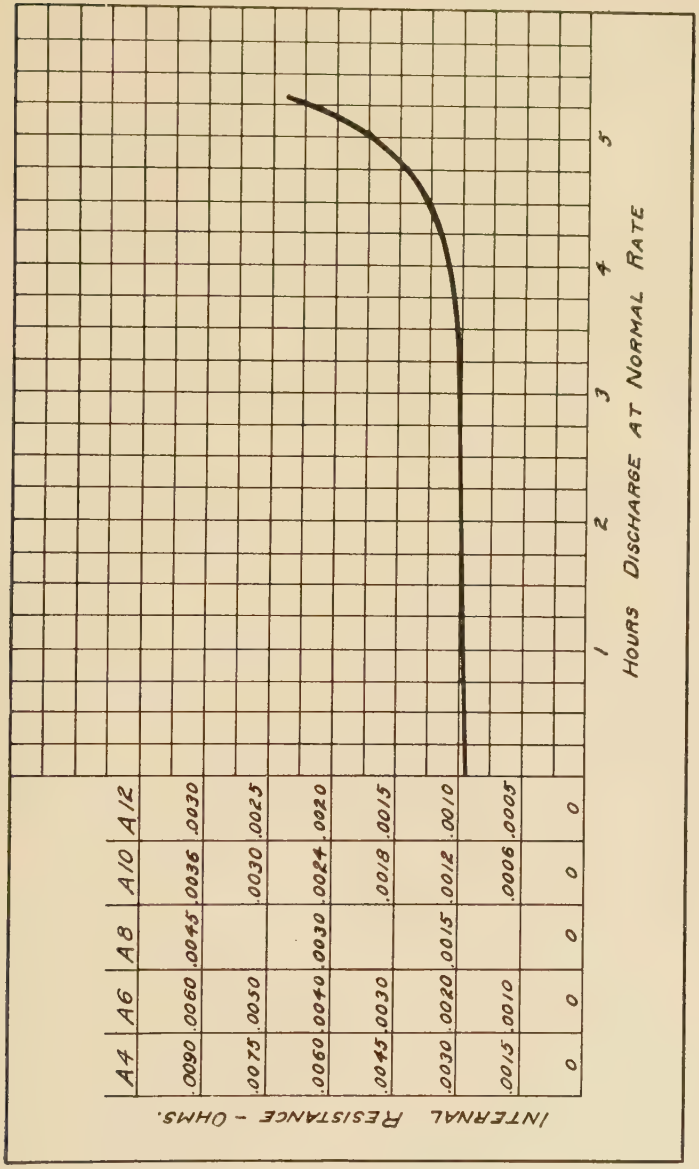


FIG. 33.—Variation of resistance of the nickel-iron cell.

action begins at the surface and moves back into the plate as the discharge proceeds. The acid within the pores is used up in forming the sulphate on the plate and can be replaced only by diffusion. The particles of active material are partly covered with the newly formed sulphate whose resistance is comparatively high. During charge the electrolyte within the pores becomes more concentrated as the charge proceeds. The active material near the surface is the first to be changed, but its resistance is lower than that of the sulphate from which it has been converted.

The resistance of sulphuric acid, of density equal to that used as electrolyte, between opposite faces of a cube 1 in. on a side, is about 0.6 ohm. In order to obtain an idea of the resistance of a cell we may assume that we have a cell with eleven plates, each 7¾ in. by 7¾ in. and ¼ in. apart. The number of positive plates in this cell is five, and the acid area from positive to negative plates equals ten times the area of each plate or 600 sq. in. The resistance between terminals of this cell is then found by multiplying 0.6 ohm by ¼ and dividing by 600 which gives us the very low value of 0.00025 ohm. The normal charge rate of this cell is 10 amp., and the voltage drop due to the resistance of the electrolyte between plates is but 0.0025 volt.

56. Effect of Internal Resistance on Output of Cell.—It is an interesting fact that the output of a battery is a maximum when the discharge rate is such that the terminal voltage equals one-half the battery voltage. In other words the output of a battery in watts is the greatest when the terminal voltage and the drop in potential due to the internal resistance are equal.

The internal resistance of a type A Edison cell under certain conditions may be taken as 0.012 ohm per positive plate. The rated ampere-hours per positive plate is 37.5, and the normal or 5-hour rate of discharge is 7.5 amp. Table VI shows the current, the internal resistance drop, the terminal voltage, and the output in watts for an Edison cell with one type A positive plate under the assumption stated above, with an initial or no load voltage of 1.20 volts.

TABLE VI.—CHARACTERISTICS OF EDISON CELLS

Amperes	Internal resistance drop	Terminal volts	Watts output
10	0.12	1.08	10.8
20	0.24	0.96	19.2
30	0.36	0.84	25.2
40	0.48	0.72	28.8
50	0.60	0.60	30.0
60	0.72	0.48	28.8
70	0.84	0.36	25.2
80	0.96	0.24	19.2
90	1.08	0.12	10.8
100	1.20	0.00	00.0

The above table shows that the maximum output is 30 watts, and that it is obtained when the rate of discharge is 50 amp. This is a little more than six times the normal rate of discharge. The maximum current which can be obtained on short circuit is 100 amp. or about thirteen times the normal discharge rate. If, for example, we take a type A4 cell which has four positive plates, the internal resistance will be one-fourth as much as for one plate, the maximum possible current will be about 400 amp., and the maximum power will be about 200 watts.

The voltage drop in the lead-acid cell is about 0.05 volt at the normal or 8-hour rate. Since the e.m.f. of the cell is two volts we may say that the maximum current which it can deliver on short-circuit is forty times the normal discharge rate, and the maximum power output is obtained when the current is about twenty times the normal rate.

In view of these facts it may readily be seen that the lead-acid cell is preferable where the current demands will be large for a short time, as for the electric starting systems of automobiles.

57. Freezing of Electrolyte.—Electrolyte of sulphuric acid freezes (forms a slush) at higher temperatures the lower the specific gravity. A completely discharged cell is,

consequently, more likely to freeze than one which is fully charged. The following table shows the relation between freezing point and density:

Specific Gravity	Freezing Point, Degrees Fahr.
1.050	26 above zero
1.100	18 above zero
1.150	5 above zero
1.200	17 below zero
1.250	62 below zero
1.300	95 below zero

The jars and plates may be injured if a cell is allowed to freeze.

The electrolyte of the Edison cell, potassium hydroxide or caustic potash, forms a slush, like snow ice, at 20 deg. below zero.

58. Capacity of Storage Cells.—The capacity of a cell may be expressed in terms of the quantity of electricity

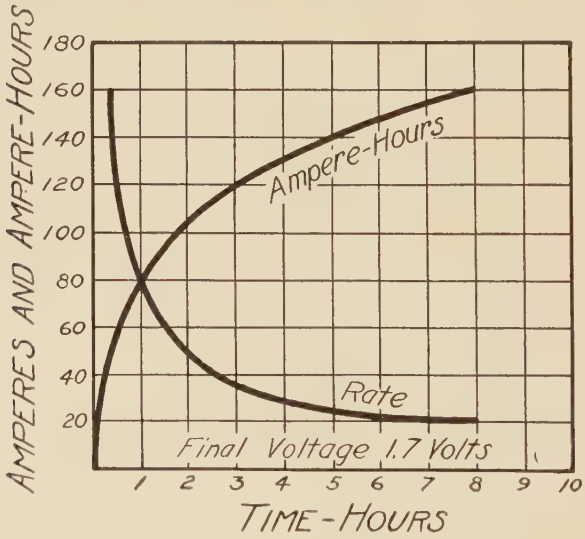


Fig. 34.—Output at different rates.

required to discharge it at the normal rate or in terms of the energy that may be obtained from the cell if discharged at the normal rate. The first is known as the ampere-hour capacity and the second as the watt-hour capacity. The

ampere-hour capacity of a cell depends upon the number, thickness, and area of the positive plates. In other words, the capacity depends upon the amount of convertible active material on the plates.

The capacity of lead-acid cells varies widely with the rate of charge and discharge. At discharge rates lower than normal the capacity of the cell is greater and at rates of discharge higher than normal the capacity is less than at

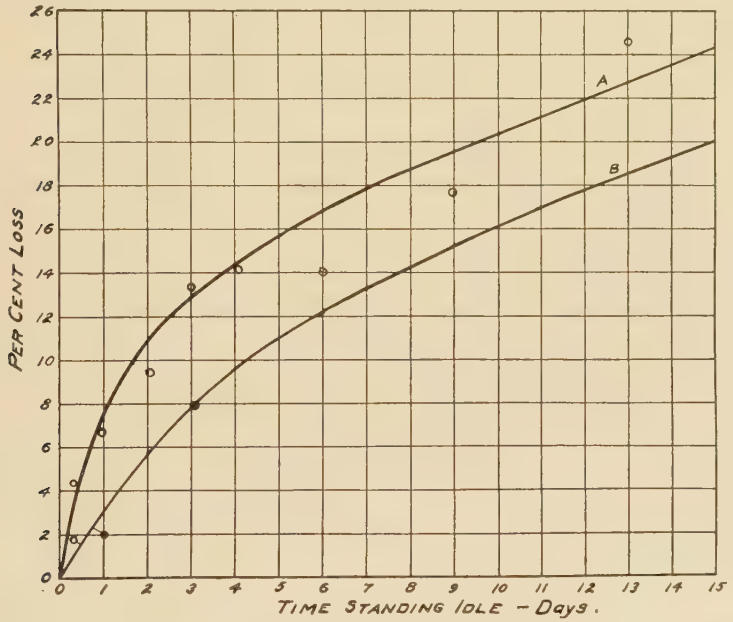


FIG. 35.—Loss of capacity of cells when standing idle. Curve *A*, nickel alkaline cell, curve *B*, lead acid cell.

normal rates of discharge. These characteristics are shown in Fig. 34.

The capacities of all kinds of storage cells decrease while standing idle. The percentage loss of capacity with different periods of idleness is shown in Fig. 35. This loss in capacity may be due to the formation of crystals of sulphate within the active material in the lead-cells. In the nickel-iron cells a slow oxidation of iron takes place which is not so easily reduced on charge as the oxide formed by the discharge of the cell. To restore the lead-cell to its normal

capacity it is necessary to give it an overcharge. In extreme cases several cycles of charge and discharge may be required before all of the sulphate crystals have been decomposed. To restore the nickel-iron cell to full capacity, discharge it at a normal rate to as low voltage as possible; then short-circuit it for at least 5 hours. Charge the cell at the normal rate for not less than 15 hours and discharge it at the normal rate again to as low voltage as possible, but do not short-circuit. The cell should then be charged at normal rate for not less than 12 hours.

The capacity of both types of cells also decreases with temperature. This decrease also varies with rate of discharge. For the lead-acid cell this decrease is nearly uniform between 68 deg. Fahr. and 32 deg. Fahr. and is approximately ¾ of one per cent per deg. Fahr. when the cell is discharging at the 5-hour rate.

The decrease of capacity with temperature is more marked in the nickel-iron cell. The change in capacity is not uniform with temperature as in the lead cell, but below a certain critical temperature, which varies with the rate of discharge, the decrease in capacity is very great; while above this critical temperature nearly the full capacity of the cell may be obtained. At the normal rate of discharge the critical temperature appears to be in the neighborhood of 41 deg. Fahr.

Since the capacity of the cell depends upon the quantity of active material that is available, it is evident that the capacity will decrease if the amount of active material grows less. The active material of a new cell first increases with a consequent increase in capacity; later it is gradually shed and thus the capacity will decrease with the age of the cell. The decrease due to the loss of material will be much more marked if the cell has been charged and discharged at excessively high rates, and overcharged for long periods.

When storage cells are connected in series, the ampere-hour capacity of the battery is equal to the ampere-hour capacity of a single cell. The watt-hour capacity of a

battery is equal to the ampere-hour capacity multiplied by the average voltage of the total number of cells in series.

59. Efficiency of Storage Cells.—By efficiency of any machine or mechanism is usually meant the ratio of the output of the machine to the input. The input and output of a storage cell may be measured in either ampere-hours or watt-hours. There are thus two bases for efficiency ratings. The ampere-hour efficiency is the ratio of the ampere-hours obtained from the cell to the ampere-hours required to charge it.

$$\text{Ampere-hour efficiency} = \frac{\text{ampere-hours taken out}}{\text{ampere-hours put in}}.$$

If the charging is stopped before any water is decomposed, and the active material is completely reversible, theoretically the cell should give out as many ampere-hours as are required to charge it. In practice this efficiency is not reached, although efficiencies of approximately 99 per cent for short periods of charge have been obtained.

The watt-hour or energy efficiency is the ratio of the energy output to the energy input in watt-hours.

$$\text{Watt-hour efficiency} = \frac{\text{watt-hours output}}{\text{watt-hours input}}.$$

The reason for the much lower watt-hour efficiency is the energy loss in the internal resistance of the cell and the fact that the counter voltage of the cell on charge is higher than on discharge. Curves, Fig. 36, show the relations of both the ampere-hour and the watt-hour efficiencies to duration of charge for the nickel-iron cell. It will be observed that for short periods of charge at normal rate both efficiencies are relatively high, but fall off with increase in the duration of charge. The decrease in the efficiencies beyond the 7-hour period of charge is primarily due to the decomposition of the water.

A long period of charge at normal and above normal rate is wasteful in two ways: The efficiency of the cell is reduced, and water must be added to the cell more often to replace

that decomposed. For example, Fig. 36 shows that the ampere-hour efficiency for a 7-hour period is 82 per cent. This means that 82 per cent of the electricity passing through the cell is active in converting the active material and 18 per cent does no useful work. This 18 per cent is used primarily in decomposing water. The total input for the seven hours is 210 ampere-hours. Eighteen per cent of this is 38 ampere-hours, which amount is wasted in

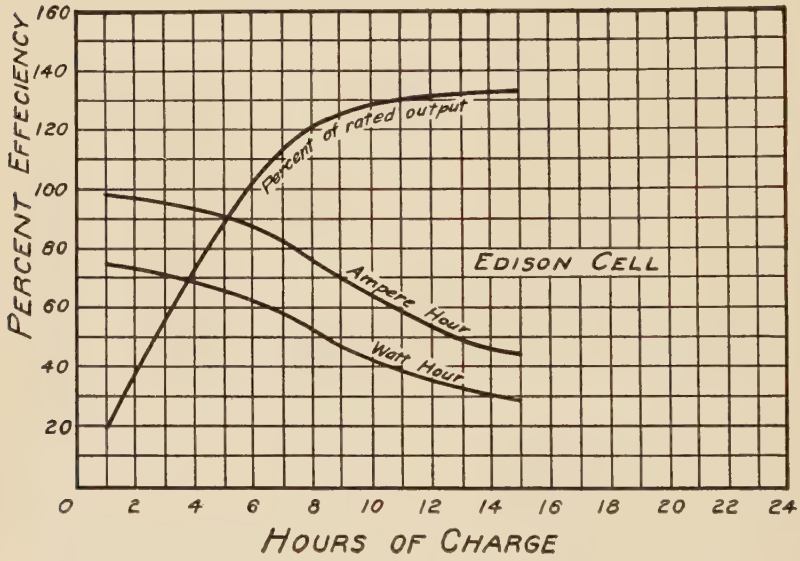


FIG. 36.—Variation of efficiency with different rates of charge.

decomposing water. The corresponding figures for a 10-hour period of charge are an efficiency of 64 per cent, loss of 36 per cent, and a total charge of 300 ampere-hours. The amount of electricity used in decomposing the water in the second case is 36 per cent of 300 ampere-hours which is 108 ampere-hours. These 108 ampere-hours decompose nearly three times as much water as the 38 in the first case, showing that a cell which is worked continually on a 10-hour normal current charge will require the addition of water about three times as often as one worked continually on the normal 7-hour charge. The same general principles apply to the lead cell.

Referring to the watt-hour efficiency curve it will be observed that the energy efficiency is 15 per cent lower when the cell is charged for 10 hours than when charged for 7 hours. Most of this 15 per cent of energy is wasted in decomposing the water. This is further illustrated by Fig. 37, which shows characteristic voltage discharge curves for a cell at its rated output, normal output, and overcharge output. These curves show that when the cell

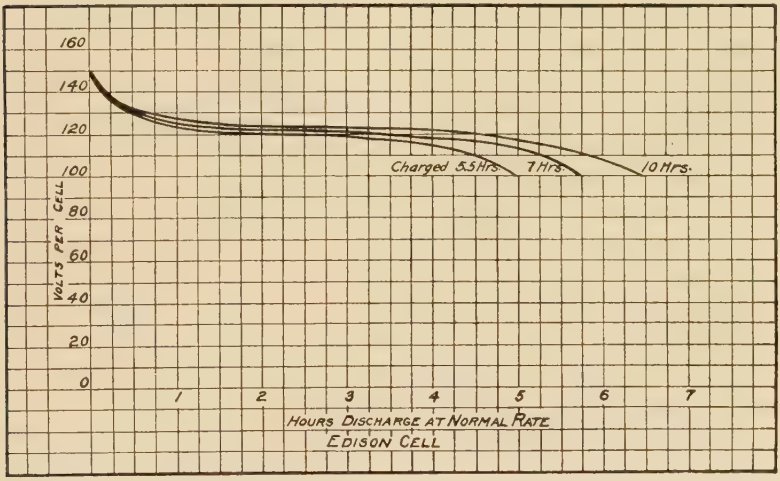


FIG. 37.—Variation in terminal voltage of the nickel-iron cell with different rates of charge.

is charged at normal rate for 5½ hours, the rated output is obtained in 5 hours, and the efficiencies under these conditions are relatively high. When the charging period is prolonged to 10 hours, the output per pound of cell is materially increased, but this is realized at a sacrifice of efficiency.

The efficiencies of the lead cell also vary with the rates of charge and discharge and for much the same reasons as those that apply to the nickel-iron cell. Owing to the slowness with which the electrolyte diffuses, the voltage curve drops much more rapidly on high than on low discharge rates. This is disclosed by the curve of Fig. 38

which shows that the ampere-hour output decreases rapidly as the rate of discharge is increased. The ampere-hour efficiency for the same cell and corresponding to the rate

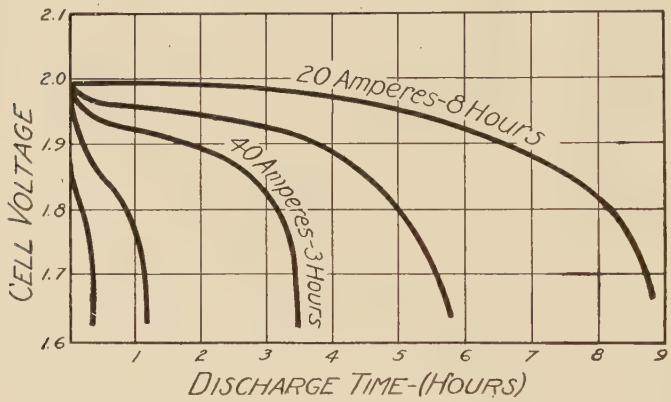


FIG. 38.—Variation of ampere-hour output with discharge rate.

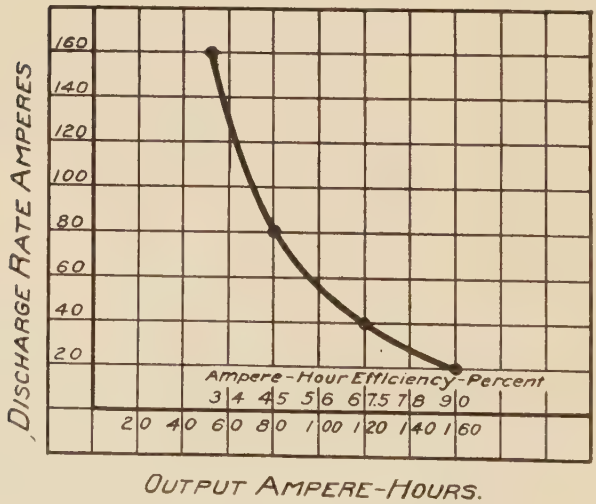


FIG. 39.—Ampere-hour efficiency and discharge rate.

of discharge is shown in Fig. 39. The cell was charged at a low rate and discharged at constant temperature. The energy efficiency also decreases with high charging and

discharging rates. Both ampere-hour and watt-hour efficiencies are reduced by the following causes:

(*a*) *Gassing.*—Any gassing of the battery means that ampere-hours are being put into it and expended in dissociating water, and since the gas escapes into the air, the ampere-hours so expended will never be regained. Since gassing occurs only for a short period near the end of the charge and then only with a reduced value of current its effect on the ampere-hour efficiency is not so serious as it might appear to be.

(*b*) *Local Action.*—By local action is meant a discharge within the cell. This action is due to impurities such as iron, copper, arsenic, tin, antimony, or any of the metals. If these are present, small electrolytic cells are formed which cause self-discharge of either plate. In order to reduce the probability of this occurring, it is advisable to secure electrolyte for storage cells from the manufacturers who specialize in this branch of the business. Water used to replace that which has been lost by evaporation from the electrolyte should be clean and pure; only distilled water or water that is known to be free from injurious substances should be used.

(*c*) *Leakage.*—Leakage of current due to poor insulation of the containers is another source of loss and reduced efficiency. Clean containing vessels and well-insulated supports tend to reduce this leakage. In the case of large central station cells with lead lined tanks, any serious leakage of current from one cell to another will soon eat a hole in the lead lining and serious results will ensue.

60. Specific Output.—The energy output of a cell depends upon many factors as disclosed in the preceding paragraphs. For certain classes of service, and in judging the relative merits of storage cells of different kinds, it is sometimes important to know the energy output per pound of cell, or per unit volume, such as a cubic foot. Figure 40 shows the watt-hours output of the Edison cell per pound of cell at different discharge rates, while Fig. 41 shows the variation of watt-hours output per cubic foot at different

rates of discharge. The normal specific output per pound of material is slightly above 15 watt-hours, and the normal specific output per cubic foot is nearly 1,300 watt-hours.

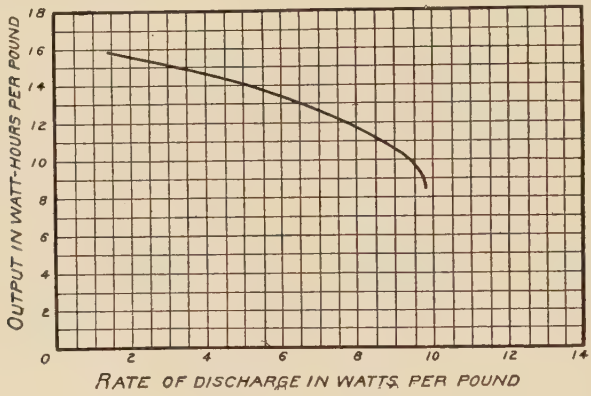


FIG. 40.—Specific output per pound of cell.

The specific output of the lead-acid cell varies widely, depending upon the thickness of plates and container.

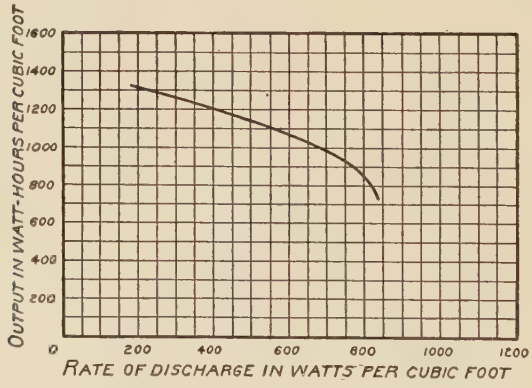


FIG. 41.—Specific output per cubic foot of cell.

61. Factors Affecting the Voltage of a Cell.—In discussing the voltage of a cell a distinction must be made between the open circuit voltage and the closed circuit voltage. The open circuit voltage is the actual e.m.f. between the terminals of a cell when no current is flowing

through it. The closed circuit voltage is the e.m.f. at the terminals of the cell when a current is flowing.

The terminal voltage of a cell is always higher when it is being charged than when it is discharging. A part of this variation in voltage is due to the change in the density of the electrolyte. The resistance of the electrolyte to the passage of current accounts for most of the variation. If an attempt be made to slide a weight up an inclined plane, the force exerted must equal the component of the weight down the plane plus the frictional resistance. This is analogous to the condition in a cell when current is forced through it against its electrical pressure as in charging. On the other hand, when the weight is sliding down the inclined plane it can exert a force equal only to the difference between its downward component and the frictional resistance it encounters in sliding. This effect is similar to the conditions in a cell when it is being discharged. The voltage of a storage cell does not remain constant during charge or discharge but varies considerably. These variations are due to several factors, among the more important being the following:

(*a*) Density of electrolyte
(*b*) Temperature
(*c*) Rate of charge and discharge
(*d*) Types of plates
(*e*) Previous treatment.

If curves be plotted showing the variations of the terminal voltage with time at constant rates of charge and discharge, they will be found to have marked peculiarities or characteristics. Typical charge and discharge curves for a cell that has been in service are shown in Fig. 42. The upper or charge curve shows that during the first hour of charge there is a rather rapid rise of voltage. This is followed by a gradual rise of voltage for the next 6 hours when another rise at an increasing rate takes place. This increase, however, ceases in about another hour; and if the charge is continued longer, the voltage remains practically constant.

The voltage curve on discharge has just the reverse characteristics; at first there is a rapid fall, followed for

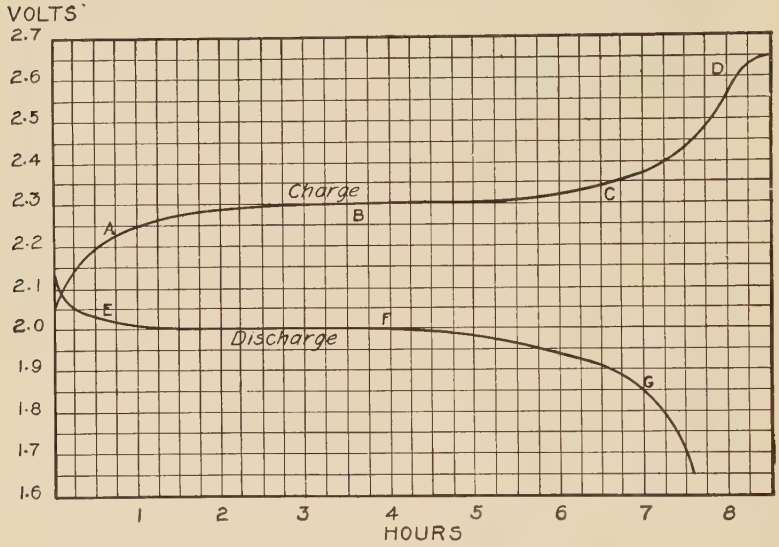


FIG. 42.—Lead-acid cell charge and discharge voltage curves.

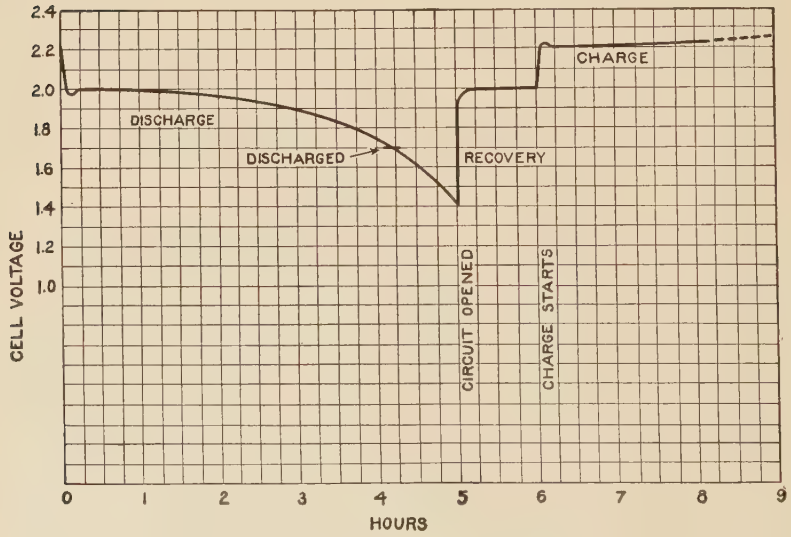


FIG. 43.—Voltage recovery curve of lead-acid cell.

several hours by a more gradual decrease, and finally a sudden drop which would extend to zero if the cell were

completely discharged. The reader must not conclude that the changes in the flexure of the curves take place after the same interval of time for every cell. The curves are typical, but the interval of time between the bends will depend upon the condition of the cell and the rate of charge or discharge. The causes of these changes in the voltage are due to the different factors mentioned above, the chief one being density of the electrolyte. If the discharged cell is left on open circuit for a time, its voltage will rise to nearly normal as shown in Fig. 43.

(*a*) *Influence of Density of Electrolyte.*—The influence of the acid concentration on the open circuit voltage has been briefly pointed out. In general, it may be said that the greater the specific gravity, the higher the voltage. Referring to the voltage curve on charge, the rather rapid rise during the first minutes of charge is due to the rapid increase in acid density at the points where the chemical reaction is taking place. This rise in voltage continues until the diffusion reduces the rate of increase in the concentration. During the interval of time represented by the distance between the points *A* and *C* on the curve, Fig. 42, the acid content of the electrolyte increases at a slower and more uniform rate. This is accompanied by a continuous but slow rise in the voltage.

(*b*) *Influence of Temperature.*—According to the kinetic theory, an increase in the temperature of a substance increases the velocity of the molecules. Increasing the temperature of the electrolyte has the same effect; namely, an increase in the activity of the molecules which accelerates diffusion and equalizes the density more rapidly. This equalization of density results in a lower voltage. The reduction in voltage resulting from an increase in the temperature of the electrolyte must not be confused with the effect of temperature on the e.m.f. of cells, which has the opposite effect. This latter is, however, so slight that it is of little practical importance, while the change in rate of diffusion of the electrolyte with changes in temperature has an important bearing on the capacity of the cell.

For example, it is well known that at low temperatures, as in winter, the apparent current capacity of a cell is greatly

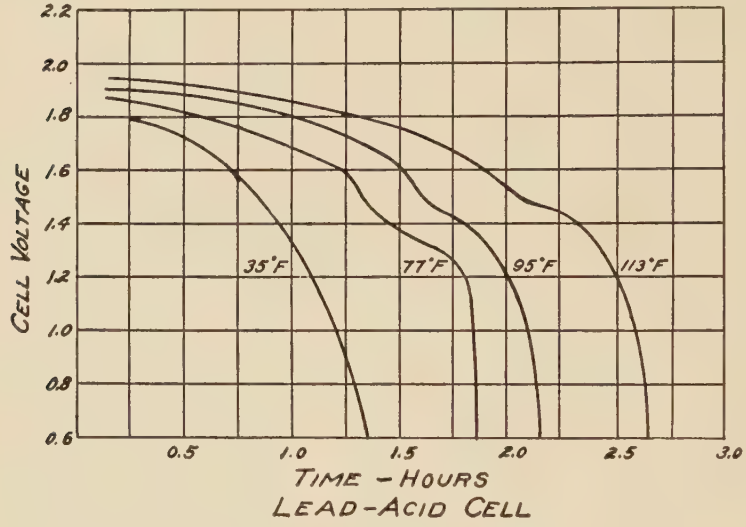


FIG. 44*a*.—Variation of voltage of lead-acid cell with temperature.

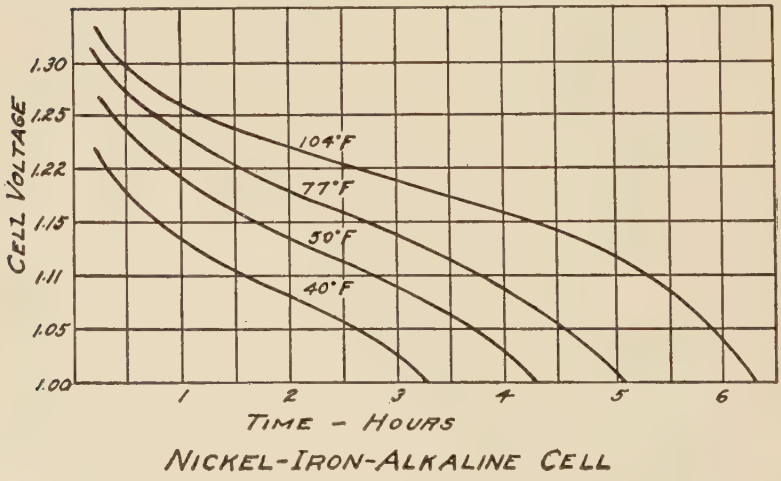


FIG. 44*b*.—Variation of voltage of nickel-iron cell with temperature.

reduced. This is due primarily to the lower rate of diffusion at the lower temperature.

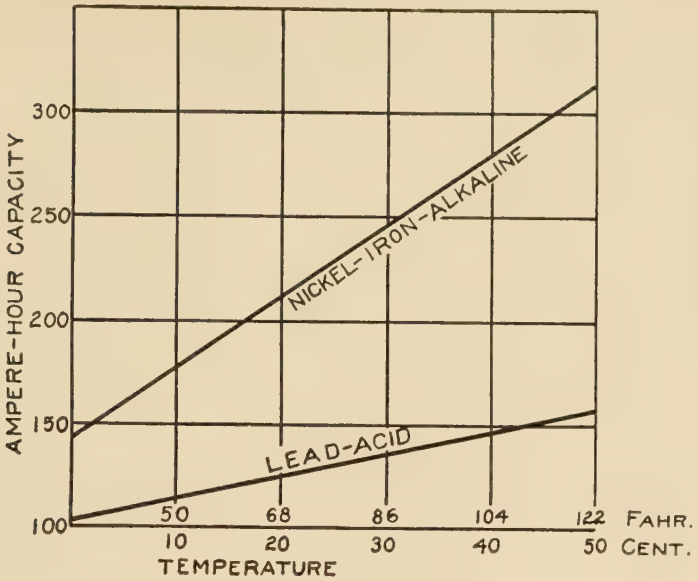


FIG. 45.—Influence of temperature upon ampere-hour capacity of lead-acid and nickel-iron cells.

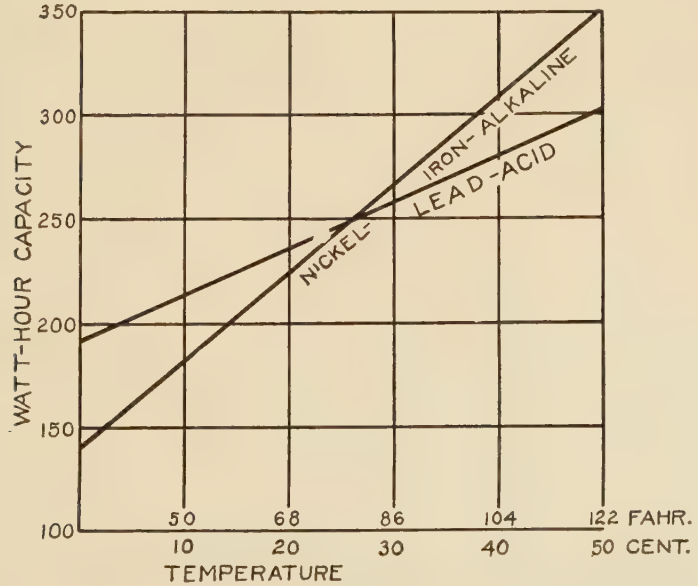


FIG. 46.—Influence of temperature upon watt-hour capacity of lead-acid and nickel-iron cells.

Changes in temperature have the same kind of influence on the nickel-iron-alkaline cell as on the lead storage cell, but as a general rule the influence is more marked.

As just pointed out the chief effect of changes in temperature is to change the rate of diffusion of the electrolyte which in turn affects the voltage and the capacity of the cell. The relations of temperature to normal voltage and to voltage drop are shown in Figs. 44*a* and 44*b*, while Fig. 45 shows the variation of ampere-hour capacity with temperature. Since the watt-hour output is the product of the ampere-hours times the average voltage, it is evident that the watt-hour capacity will vary through a wide range. This is shown by Fig. 46.

(*c*) *Rate of Charge and Discharge.*—The influence of the rate of charge and discharge may be explained as follows: Since according to Faraday's laws the chemical reactions in the storage cell vary directly with the charging current, it is evident that at high charging rates the formation of acid near and within the active material of the plate will be rapid. This rapid formation of acid increases the density of the electrolyte at the active material and makes a steeper voltage curve.

(*d*) *Types of Plates.*—The condition and type of plates have a marked influence on the shape of the voltage curves. If the plates have a small amount of active material, it will be converted much more quickly than when the amount of active material is large. The portion of the curve between *A* and *C*, Fig. 42, for a plate of this kind, is, however, less steep on account of the greater ease of diffusion. If the plate has a thick compact layer of active material, the diffusing of the acid through the interstices will be slower and the voltage curve will be steeper.

(*e*) *Previous Treatment.*—The rate of rise of the voltage curve on charge and the fall of the voltage curve on discharge, as well as the time required for complete charge or discharge, are greatly influenced by the preceding discharge or charge rate. If the preceding discharge rate is high, the voltage drops to the limiting value, on

account of the slowness of diffusion, before all of the active material is converted. On charge, such a cell will have a steeper voltage curve, and the voltage will reach a maximum value sooner than if the cell had been discharged at a low rate. From the preceding explanations the conclusion can be drawn that the rise and fall of the voltage curve are due to changes in the density of the electrolyte, and that the effects of the preceding four factors are manifested through their influence on this density. This is a satisfactory explanation of the shape of the curve from *A* to *C*, Fig. 42, but the rather sudden increase in voltage at *C* cannot be explained on this basis, and hence the cause must be sought elsewhere. Referring to the equation for the chemical reaction it is observed that on charge the lead sulphate is converted into lead and lead peroxide. Near the completion of the charge there begins to be a deficiency of lead ions to carry the current, and a higher e.m.f. is necessary to liberate hydrogen from the solution. This decrease in the supply of lead ions is shown by the increase in the voltage curve from *C* to *D*. At the point *D* no more lead is being set free and the e.m.f. necessary to force a current through the cell is the e.m.f. necessary to decompose acidulated water plus the resistance voltage drop through the cell. When this stage has been reached, the charge is complete.

RECAPITULATION

1. By discharge rate is meant the constant current which will reduce the voltage to a definite value within a specified time. The lead cell is assumed to be discharged when its final voltage is 1.7 volts; and the nickel-iron cell is assumed to be discharged when its voltage is 0.9 volt.

2. The time required to discharge a lead cell at normal rate is 8 hours for stationary cells and 5 or 6 hours for portable cells. For nickel-iron cells the time is either 4¾ hours or 7 hours, depending upon the class of cell.

3. The internal resistance of a cell is that factor by which the square of the current flowing through the cell must be multiplied to get the energy converted into heat. The internal resistance of both the lead and the nickel-iron cell, when fully charged, is low, being a small fraction of an ohm.

4. By ampere-hour capacity of a cell is meant the number of ampere-hours that the cell will discharge at normal rate.

5. The watt-hour capacity of a cell is equal to its ampere-hour capacity multiplied by its average voltage.

6. The ampere-hour efficiency of a cell is equal to the number of ampere-hours output divided by the number of ampere-hours input. The watt-hour efficiency is equal to the number of watt-hours output divided by the number of watt-hours input. The ampere-hour efficiency is invariably higher than the watt-hour efficiency.

7. Both the ampere-hour and the watt-hour efficiencies decrease as the rate of charge and discharge is increased and vice versa. The change in efficiency is not directly proportional to the change in rate of discharge.

8. By specific output is meant the energy per pound or per unit volume of a cell.

9. The voltage of a cell varies with the density of the electrolyte, temperature, rate of charge and discharge, type of plates, and previous treatment.

QUESTIONS

1. (*a*) Explain what is meant by rate.

(*b*) What is meant by normal charging rate?

2. (*a*) What is supposed to be the discharged voltage of a lead-acid cell?

(*b*) Of a nickel-iron cell?

3. What is the period of discharge of an Edison cell at normal rate?

4. Give some objections for charging at too high rate.

5. Upon what factors does the internal resistance of a cell depend?

6. Why does the resistance of a cell increase on discharge?

7. Explain what is meant by ampere-hour capacity.

8. Upon what factors does the ampere-hour capacity of a cell depend?

9. What effect does temperature have upon the ampere-hour capacity of cells?

10. How does the capacity of a cell vary with rates of charge and discharge?

11. In what respects does the variation in capacity with temperature of a nickel-iron cell differ from that of a lead cell?

12. The temperature of a lead cell has decreased from about 70 deg. to 50 deg. Fahr. What will be its percentage capacity at the lower temperature as compared with the capacity at the higher temperature?

13. What is meant by watt-hour capacity?

14. What is the watt-hour capacity of five 100 ampere-hour cells if the average voltage is 1.9 volts?

15. What is meant by efficiency?

16. Define ampere-hour efficiency.

17. Define watt-hour efficiency.

18. What is the ampere-hour efficiency of a cell that is charged for 10 hours at a constant rate of 20 amp., and discharged in 5 hours at 30 amp.? If the average voltage on charge is 2.2 volts and on discharge 1.95 volts, what is the watt-hour efficiency of the cell?

19. Why is the ampere-hour efficiency always higher than the watt-hour efficiency?

20. What is the effect of excessive gassing upon efficiency?

21. Explain the influence of local action and leakage upon the efficiency.

22. Discuss briefly the influence of the following conditions on the voltage of a lead cell:

(*a*) Density of electrolyte

(*b*) Temperature

(*c*) Previous treatment.

CHAPTER VI

CHARGING AND CARE OF STORAGE BATTERIES

62. General.—In order that storage batteries shall give the service that may reasonably be expected, they must be inspected, tested, and charged regularly and a record of the condition and behavior of the different cells kept. By such a procedure a defective cell can be located easily, and the necessary additional charge, repairs, and replacements made before the cell is ruined.

63. Cell Connections and Polarity of Circuits.—The voltage necessary for charging storage batteries depends

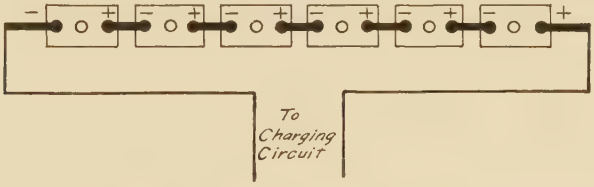


Fig. 47.—Series connection of cells.

upon the number of cells and the manner in which they are connected. The normal e.m.f. of a lead cell is from 2 to 2.2 volts. If the cells are connected in series, Fig. 47, the e.m.f. between the outside terminals is equal to the number of cells times 2 volts; for example, 12 volts. If the charging voltage is to be at least 2.6 volts per cell, the total voltage necessary to charge a group of cells in series is 2.6 times the number of cells; for six cells this is 15.6 volts.

When cells of a group are connected with their like poles together, as indicated in Fig. 48, they are said to be connected in parallel. Under these conditions the voltage between the terminals is equal to the voltage of one cell, but the charging current is equal to the sum of the currents flowing through the separate cells. To charge cells con-

nected in parallel requires an exceedingly low voltage; and if the number of cells is large, an excessively high current. The best practice is to connect enough cells in series so that their combined voltage is somewhat less than the voltage of the charging source, and enough series groups

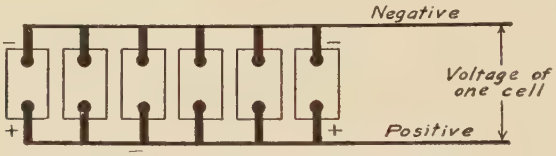


FIG. 48.—Parallel connection of cells.

in parallel so that the combined charging current does not exceed the current capacity of the charging generator, Fig. 49.

The current that a charging e.m.f. will send through a series of cells is equal to the difference between the applied and battery voltages divided by the resistance of the charging circuit including the battery resistance.

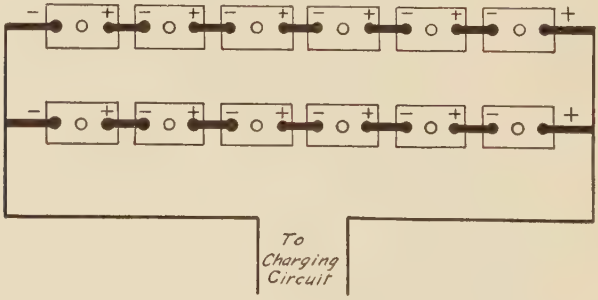


FIG. 49.—Series-parallel connection of cells.

EXAMPLES

1. A direct e.m.f. of 110 volts is available for charging 45 cells in series. What current will flow if the e.m.f. of each cell is 2 volts, the internal resistance 0.02 ohm per cell, and the rheostat has a resistance of 0.5 ohm?

SOLUTION

The applied e.m.f. is 110 volts. The battery e.m.f. is $2 \times 45 = 90$ volts.

The internal resistance is $0.02 \times 45 = 0.9$ ohm.

The total resistance is $0.9 + 0.5 = 1.4$ ohms. The charging current is, therefore,

$$I = \frac{110 - 90}{1.4} = \frac{20}{1.4}$$
$$= 14.6 \text{ amp.}$$

2. Thirty-five cells are to be charged from a 100-volt direct-current source. What must be the resistance of the rheostat if the current is not to exceed 20 amp.? Each cell has an e.m.f. of 2 volts and an internal resistance of 0.02 ohm.

SOLUTION

The resistance of the battery is $0.02 \times 35 = 0.7$ ohm. The battery e.m.f. is 70 volts.

Hence, if R is the rheostat resistance,

$$R + 0.7 = \frac{100 - 70}{20} = 1.5 \text{ ohms}$$

and

$$R = 1.5 - 0.7 = 0.8 \text{ ohm.}$$

3. Thirty-six cells are to be charged from a 50-volt source. How are they to be connected and what must be the rheostat resistance if the current is not to exceed 20 amp. per cell? Other data are the same as in Example 2.

SOLUTION

If the cells are connected in series, the battery voltage is $2 \times 36 = 72$ volts. Since this is higher than the charging voltage this connection cannot be used. Connecting the cells in two groups of 18 cells each gives a battery voltage of $2 \times 18 = 36$ volts. This is less than 50 and, hence, this connection may be used. The internal resistance of each series group equals $0.02 \times 18 = 0.36$ ohm; but as the two groups are connected in parallel, the total resistance is ½ of 0.36 = 0.18 ohm. The current in each group is to be 20 amp.; hence the total current is 40 amp. The rheostat resistance, R, is then given by

$$R + 0.18 = \frac{50 - 36}{40} = 0.35 \text{ ohm}$$

and

$$R = 0.35 - 0.18 = 0.17 \text{ ohm.}$$

64. Simple Methods of Determining Polarity.—In charging storage cells the positive terminal of the circuit must be

connected to the positive terminal of the battery. Unless the positive terminal of the charging circuit has previously been determined and marked, it becomes necessary to determine this before connecting it to the charging circuit. In case of necessity some one of the following simple methods may be used:

(*a*) *Voltmeter.*—A voltmeter of the direct-current type usually has one terminal marked with the plus sign. When this terminal is connected to the positive terminal of the circuit, the needle swings up the scale. Otherwise, the deflection of the needle is reversed.

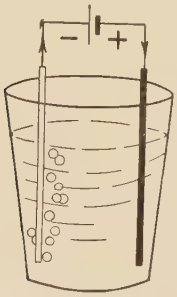


FIG. 50.—Simple test for polarity.

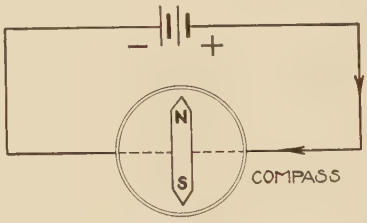


FIG. 51.—Test for polarity.

(*b*) *Ammeter.*—When an ammeter connected in series with a circuit indicates properly, the current is flowing through it from the terminal marked with the plus sign to the other terminal, the latter being the negative terminal of the circuit. A high resistance or other current limiting device must be connected in series with the ammeter.

(*c*) *Electrochemical.*—The passage of a current through an electrolyte decomposes it, and the character of this decomposition may be used to indicate the direction of current flow. The simplest application of this principle for testing the polarity of low voltage circuits is to insert the two wires of the circuit into a raw potato and observe at which terminal the potato turns green. This is the positive terminal. The cause of the green color is the copper which is removed from the wire by the current. If this method is employed, care must be taken not to short-circuit the source

of the current. Either a resistance must be connected in series or the ends of the wires must not be brought into contact.

Another application of the principle is to immerse the two wires in some electrolyte in a glass tumbler. The current decomposes the electrolyte, the hydrogen going to the negative terminal and the oxygen to the positive terminal. The positive terminal is that at which the smaller amount of gas is liberated, Fig. 50.

(*d*) *Compass Indicator.*—If the north-seeking end of a compass needle points away from the observer, when the compass is placed above a wire carrying a small current, then the direction of current flow is from right to left and the right-hand end of the wire is positive with respect to the left-hand end, Fig. 51.

65. Nomenclature of Charging.—In principle, all processes or methods of charging are essentially the same. There have, however, grown up in practice processes of charging which have been given distinctive names. This is particularly true with reference to charging vehicle batteries. The more common processes are known as *bench charge, equalizing charge, conditioning charge, boosting charge* and *trickle charge.*

A *bench charge* is the process of charging a vehicle battery from a source outside of the car. It evidently received its name from the fact that the batteries are usually placed on a bench.

An *equalizing charge* is one given the batteries at regular intervals following a bench charge. The object of this charge is to reduce any remaining lead sulphate, or, in other words, to equalize the chemical conditions of the several cells. This charge is given vehicle batteries once a week. The charging rate is about one-half the finishing rate, and it should be continued until all the cells are gassing freely.

A *conditioning charge,* sometimes called *initial charge,* is one given to a battery immediately after assembling and before putting into service. The rate is very low and is usually continued for about four days.

A *boosting charge* is a high rate charge continued for a short time. It is applied only to vehicle and locomotive batteries at such times as they are idle, and preceding use, such as the noon hour.

A *trickle charge* is a prolonged charge at an extremely low rate. It is applied to batteries in wet storage.

66. Charging Storage Batteries.—In order to charge a storage cell an electric current must be passed through it from the positive to the negative plates. This current must pass continuously in the same direction during the period of charge and, consequently, only direct current can be used. When a direct-current generator is not available, and an alternating current is available, the alternating current must first be rectified by means of some of the appliances discussed later. Persons who have had no experience with storage batteries sometimes assume that the addition of electrolyte is a method of charging. While the electrolyte must be maintained at the proper level and density, it is evident that the real sources of the current from a storage cell are the plates. The charging current restores the plates to the proper condition and enables them to give out approximately as much electricity as is passed through the cell on charge. Charging is thus an electrochemical process as previously explained.

Electricity will flow between two points on a conductor only when a difference of electrical pressure exists between the two points. As a storage cell has a voltage of its own, it is evident that to force a current through the cell in opposition to its pressure requires the application of an e.m.f. high enough to overcome the cell voltage and to compensate for the voltage drop along the connectors and through the cell. Since the charging current must flow against the e.m.f. of the cell, this e.m.f. opposes the flow of the charging current in much the same manner as the pressure of the water in an elevated tank opposes the pressure of the pump which is filling the tank. This means that the charging pressure per cell must be from 0.5 to 0.7 volt higher than the normal cell voltage. If the charging voltage

is too high, either a resistance or some other means must be inserted in the circuit to reduce the voltage to the required value. This, in general, means inefficient charging. For efficient charging the pressure per cell should not exceed 2.5 to 2.7 volts.

67. Methods of Charging.—It is entirely practical to charge storage cells at different rates and still obtain satisfactory results, provided certain limitations are not exceeded. Practical conditions of charging are such, however, that only two methods are in general use. These are known as

(*a*) Constant current

(*b*) Constant voltage or potential.

These terms are self-explanatory and indicate the general characteristics of the methods. Some explanation of the practical details will help in their application.

(*a*) *Constant Current Method.*—As the name indicates, when this method is used the current is kept at a constant value by means of a variable resistance rheostat in series with the battery or by varying the voltage of the charging generator. The voltage curves, Figs. 31 and 43, show that the voltage of both kinds of storage cells increases with charge. The current that can be sent through the cell is equal to the difference between the applied voltage and the voltage of the cell divided by the resistance of the battery and other apparatus in the circuit. Algebraically, this relation can be expressed as follows:

$$\text{Charging current} = \frac{\text{applied voltage} - \text{battery voltage}}{\text{resistance of circuit} + \text{resistance of battery}}$$

or

$$I = \frac{E_a - E_b}{R_c + R_b}$$

where

E_a = applied voltage
E_b = cell or battery voltage
R_c = resistance of the circuit
R_b = resistance of the battery.

It is at once apparent that if I, the current, is to remain constant while E_b changes, either E_a will have to be increased as E_b increases, or R_c will have to be decreased. The fact that R_b diminishes with charge, decreases the magnitude of the change necessary in E_a or R_c, but the decrease in cell resistance is not sufficient to make the process automatic.

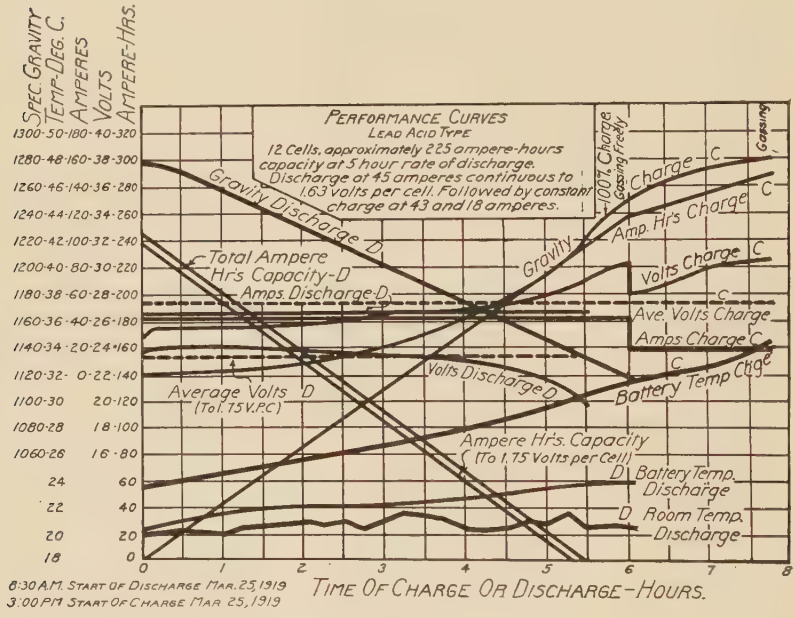

Spec. Gravity
Temp. Deg. C.
Amperes
Volts
Ampere-Hrs.
Performance Curves
Lead Acid Type
12 Cells, approximately 225 ampere-hours capacity at 5 hour rate of discharge.
Discharge at 45 amperes continuous to 1.83 volts per cell. Followed by constant charge at 43 and 18 amperes.
100% Charge
Gassing Freely
Gassing
Gravity Discharge D
Total Ampere Hr's Capacity-D
Amps. Discharge-D
Gravity C
Amp. Hr's Charge C
Volts Charge C
Ave. Volts Charge C
Amps Charge C
Battery Temp Chge C
Average Volts D (Tol. 75 V.P.C.)
Volts Discharge D
Ampere Hr's. Capacity (To 1.75 Volts per Cell) D
Battery Temp. Discharge D
Room Temp. Discharge D
1300 50 180 40 320
1280 48 160 38 300
1260 46 140 36 280
1240 44 120 34 260
1220 42 100 32 240
1200 40 80 30 220
1180 38 60 28 200
1160 36 40 26 180
1140 34 20 24 160
1120 32 0 22 140
1100 30 20 120
1080 28 18 100
1060 26 16 80
24 60
22 40
20 20
18 0
0 1 2 3 4 5 6 7 8
6:30 A.M. Start of Discharge Mar. 25, 1919
3:00 P.M. Start of Charge Mar 25, 1919
Time of Charge or Discharge—Hours.

Fig. 52.

To study the behavior or characteristics of any apparatus under different conditions of operation it is customary to vary one factor involved in the operation of the apparatus and observe how other related factors vary. The interdependence of the factors is then best disclosed by curves drawn on coordinate or cross-section paper. Thus, if the discharge rate of a cell be kept constant, the terminal voltage will fall, the temperature of the cell may change, the specific gravity of the electrolyte will decrease, the ampere-hour capacity will change, etc. It is possible to

show these changes with time at a constant discharge and charge rate by curves as in Fig. 52.[1] These curves are for a 12-cell lead-acid battery of approximately 225 ampere-hour capacity. As the line for current shows, the discharge current was kept constant at 45 amp. for 5½ hours, and during this time the voltage dropped from 2 to 1.63 volts per cell or from 24 to 19.5 volts for the battery. Likewise, the specific gravity decreased from 1,280 to

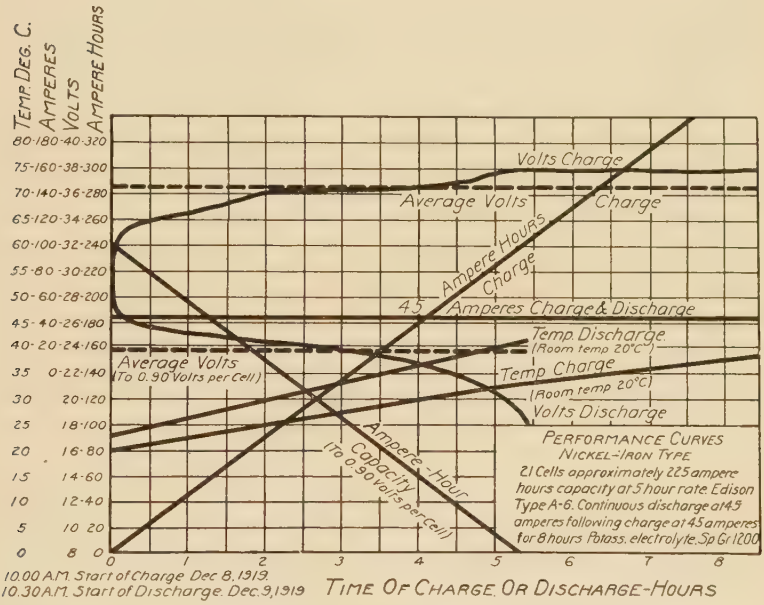


Fig. 53.

1,180, and the temperature increased from about 20.5 to 23.9 deg. Cent. while the room temperature increased slightly.

In the same figure are also shown the variations of the same quantities on charge at a constant rate of 43 amp. for 6 hours and 18 amp. for 1¾ hours longer. It is interesting to note that while on discharge the temperature increased

[1] Figures 52, 53, 55, and 56 from *Circular* 92, U. S. Bureau of Standards.

only about 3.4 deg. Cent., on charge at a lower rate the temperature rose from about 23.5 to 33.4 deg. in the same length of time, and to 34.5 deg. in 7¾ hours.

When the nickel-iron cells are charged by the constant current method, the charging current is kept constant at its normal value for the full period of time, normally 7 hours, or until the voltage has reached a steady value of 1.85 volts per cell, as the constancy of the voltage and duration of charge are the only indications of the charged conditions of the nickel-iron cell. The temperature of the cells must never be permitted to rise about 45 deg. Cent. (115 deg. Fahr.). Characteristic curves for the nickel-iron storage battery, when charged and discharged at constant rate, are shown in Fig. 53. It will be observed that the temperature curves on charge and discharge are practically parallel straight lines and that the temperature on charge changes less than on discharge. This is in marked contrast with the lead-acid cell.

(*b*) *Constant Voltage Method.*—The application of this method requires that the charging voltage per cell be kept constant. Since the counter voltage of a discharged cell is lowest at the beginning of charge, the initial charging current under this method is far in excess of the normal charging current. During the charge the voltage of the cell gradually rises and, consequently, the charging current decreases until near the end of the charge it is much less than the finishing rate under the constant current system. To prevent excessive heating, the charging current should decrease automatically so that at any instant it is less than the number of ampere-hours required to complete the charge.

The main advantage of the constant voltage method of charging is that it permits the reduction of the duration of charge below the normal period. The following examples will help to make this clear. Assume a 100 ampere-hour cell to be charged by the constant potential method as shown in the following table:

90 amperes for 20 minutes	30 ampere-hours
66 amperes for 20 minutes	22 ampere-hours
42 amperes for 20 minutes	14 ampere-hours
30 amperes for 20 minutes	10 ampere-hours
21 amperes for 20 minutes	7 ampere-hours
18 amperes for 20 minutes	6 ampere-hours
9 amperes for 60 minutes	9 ampere-hours
3 hours	98 ampere-hours

The total charge is approximately equal to the capacity of the cell and the duration of charge only 3 instead of 8 or more hours. The temperature of the cells must, however, be watched.

For batteries of the lead-acid type, the charging voltage at the cell terminals should not exceed 2.4 volts and should not fall below 2.2 volts per cell, the average being approximately 2.3 volts. At the busbars the voltage may range from 2.5 to 2.7 volts, depending upon the resistance of the connectors and other local conditions. It must be remembered that an excessive voltage at the busbars, which must be reduced by a resistance, results in wasted energy. On the other hand, if the bus voltage is but slightly higher than that of the battery, the charging current will become more or less unstable on account of the effects of temperature changes and slight changes in the busbar voltage. When, therefore, it is impossible to adjust the charging voltage to the proper value, as indicated above, the desired reduction may be obtained by the use of so-called counter-electromotive cells. In case the current capacity of the charging generator is small it is necessary to limit the initial current. This is most satisfactorily accomplished by the use of counter-electromotive force cells explained later.

There are several practical disadvantages of the constant voltage method. First, the high initial charging rate necessitates equipment of large current capacity and increases the maximum demand, which is an important factor in the cost of power. Second, the charging rate for the final 10 or 15 per cent of the charge falls so low that a long time is required to charge the cell completely unless the voltage is raised to

about 2.5 to 2.6 volts per cell. This adjustment for the end of the charge must be made by hand, so the method cannot be considered automatic. For these reasons the constant voltage method of charging has very limited practical application.

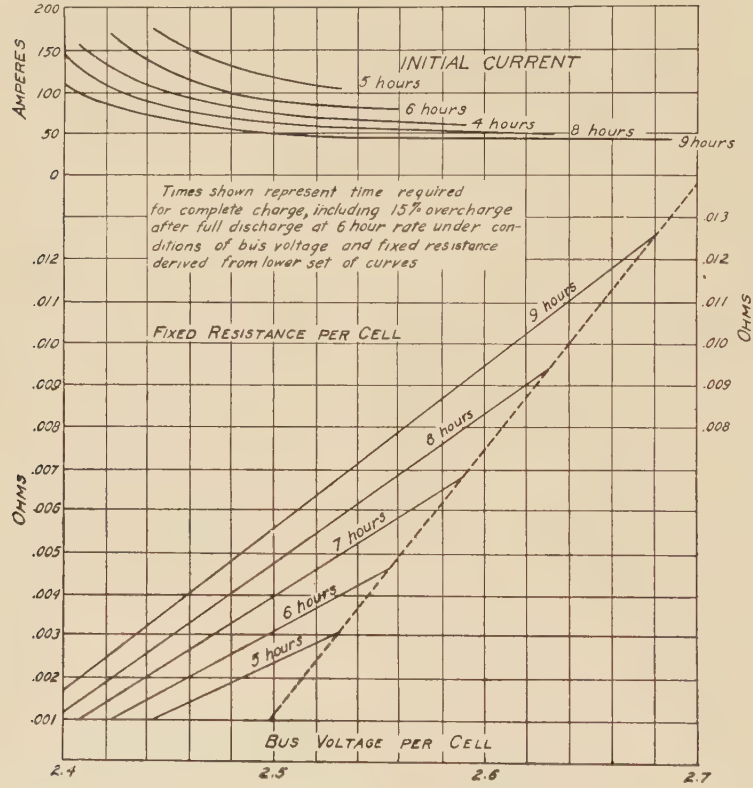


FIG. 54.—Chart for calculating charging resistance.

(c) *Modified Constant Voltage Method.*—A somewhat more satisfactory and more practical method is to use a fairly constant voltage of about 2.6 to 2.7 volts per cell. In series with the battery is inserted a fixed resistance of such value as to keep the initial charging current within the capacity of the apparatus and also as low as the time requirements will allow. After the cells start to gas, the charging current should drop to the finishing rate. This is

known as a modified constant voltage method. The fixed resistance must be low enough and the current carrying capacity of the resistor must be high enough to permit the flow of the initial current without overheating.

The value of the fixed resistance to be used in any particular instance will depend upon the busbar voltage and permissible charging current. These quantities are related, and the determination of them, when the busbar voltage per cell is known, will be facilitated by chart, Fig. 54,[1] which is made for a cell of 15 plates, and of 238 ampere-hour capacity at a six-hour period of discharge.

This chart consists of two parts: The upper part shows the permissible initial charging current for a certain period of charge and corresponding to a given busbar voltage shown on the horizontal scale at the lower edge of the chart. The lower part shows, on the vertical scale, the fixed resistance which must be used to give the required initial current at the given busbar voltage. The following examples will illustrate the use of the chart:

EXAMPLE

What fixed resistance must be used if the 238-ampere-hour cell is to be charged in 7 hours? The busbar voltage is 2.55 volts per cell. What will be the initial charging current?

SOLUTION

On the lower scale marked "Bus Voltage per Cell" find the vertical line corresponding to 2.55 volts. Follow this line vertically to its intersection with the slanting line marked 7 hours. From this point of intersection run horizontally to the left to the vertical axis. On this axis read the fixed resistance 0.0057 ohm. The initial charging current is found by following the vertical line corresponding to 2.55 volts to its intersection with the curve marked 7 hours at the top of the chart. From this intersection run to the left and read on vertical scale 65 amp. This is the initial rate.

Since the chart applies only to a cell of a specified capacity at a given rate of discharge, to make it applicable to other cells of different capacities at different rates, corrections must be made.

[1] *Bulletin* 177, Electric Storage Battery Co.

The rate of discharge for the same period of two cells of different ampere-hour capacities is directly proportional to their capacities; hence, the initial charging current of any cell may be obtained from the curve by multiplying the value read from the curve by the ratio of the capacity of the cell to be charged to 238, the capacity of the cell for which the chart is made. Since the current in a given circuit and under a given voltage varies inversely as the resistance in the circuit, the required fixed resistance for charging a cell of different capacity is obtained by dividing the resistance read from the chart by the ratio mentioned above.

EXAMPLE

Given a battery of twelve 200 ampere-hour cells when discharged for a period of 6 hours at a uniform rate. The busbar voltage is 30 volts. Determine the initial charging current for a period of 5 hours and the required fixed resistance.

SOLUTION

The busbar voltage per cell is $\frac{30}{12} = 2.5$ volts. Ratio of ampere-hour capacity of cell to be charged to 238 is $\frac{200}{238} = 0.84$.

From the chart, the initial charging current for the 238 ampere-hour cell is 117 amp., and the fixed resistance per cell is 0.0024 ohm. The charging current for the 200 ampere-hour battery is $0.84 \times 117 = 98$ amp., and the total fixed resistance is $\frac{12 \times 0.0024}{0.84} = 0.034$ ohm. A resistor of 0.04-ohm resistance and a current carrying capacity of 100 amp. will be required. In order to be able to make adjustments for variations in resistance with temperature, it is a good plan to provide taps on the resistor.

By the use of an ampere-hour meter in the charging circuit, the method may be made automatic. The ampere-hour meter is provided with an insulated contact at *zero* or *full-charge* point on the dial. The pointer of the ampere-hour meter is set at such a point on the dial that when it reaches the full charge or zero position, the contact is closed and the shunt trip coil of the circuit breaker is energized,

opening the battery circuit. If the ampere-hour meter is left permanently in the battery circuit, as in railway service, it may be provided with two contacts, one to open the circuit when the battery is discharged, and the other when it is charged. Ampere-hour meters for such service are

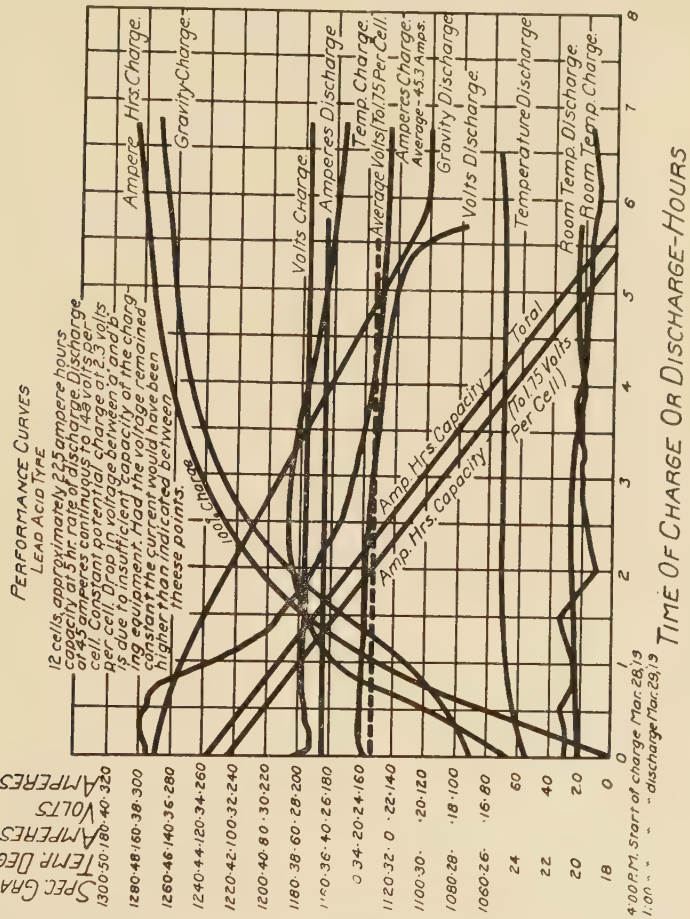

Performance Curves
Lead Acid Type
12 cells, approximately 225 ampere hours capacity at 5 hr. rate of discharge. Discharge at 45 amperes continuous to 1.42 volts per cell. Constant potential charge at 2.37 volts per cell. Drop in voltage between a and b is due to insufficient capacity of the charging equipment. Had the voltage remained constant the current would have been higher than indicated between these points.
Ampere Hrs. Charge
Gravity Charge
Volts Charge
Amperes Discharge
Temp. Charge
Average Volts (To 1.75 Per Cell)
Amperes Charge
Average - 45.3 Amps.
Gravity Discharge
Volts Discharge
Temperature Discharge
Room Temp. Discharge
Room Temp. Charge
Amp. Hrs. Capacity
Amp. Hrs. Capacity
Total
To 1.75 Volts Per Cell
Time Of Charge Or Discharge-Hours
Spec. Gravity
Temp. Deg. C.
Amperes
Volts
Amperes
4:00 P.M. Start of charge Mar. 28/13
discharge Mar. 29/13

Fig. 55.—Performance curves of lead-acid cells.

designed to run more slowly on charge than on discharge, thus automatically permitting from 10 to 25 per cent more electricity to be passed through the battery than is obtained on discharge.

The proper voltage at the busbar for the constant voltage method should be obtained by varying the excitation

or speed of the generator; and, if this is not feasible, by counter-electromotive force cells and not by a resistance.

For charging batteries of the nickel-iron type by the constant voltage method, the busbar voltage should be about 2 volts per cell so that the voltage at the cells may

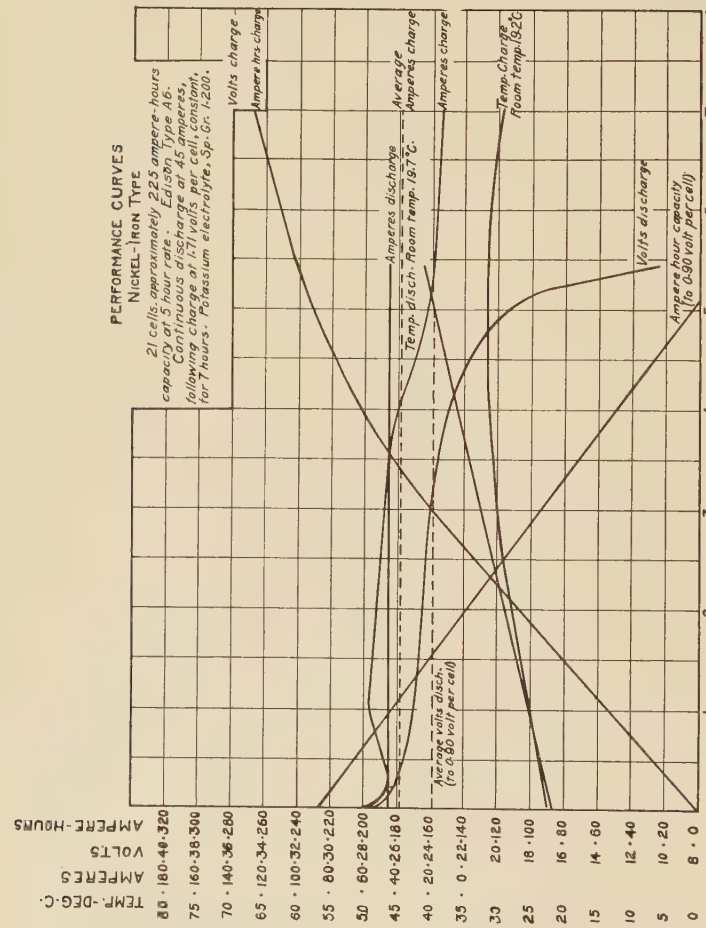

PERFORMANCE CURVES
NICKEL-IRON TYPE
21 cells, approximately 225 ampere-hours capacity at 5 hour rate. Edison Type A6. Continuous discharge at 45 amperes, following charge at 1.71 volts per cell, constant, for 7 hours. Potassium electrolyte, Sp. Gr. 1.200.
Volts charge
Ampere hrs charge
Amperes discharge
Temp. disch. Room Temp. 18.7° C.
Average Amperes charge
Amperes charge
Temp. Charge Room Temp. 19.2°C
Volts discharge
Ampere hour capacity (to 0.90 volt per cell)
Average volts disch. (to 0.80 volt per cell)
11:45 A.M. Start of charge. Dec. 16-1919
10:45 " " discharge. Dec. 17-1919.
TIME OF CHARGE OR DISCHARGE-HOURS
AMPERE-HOURS
VOLTS
AMPERES
TEMP.-DEG.-C.

Fig. 56.—Performa curves of nickel-iron cells.

never be less than 1.7 volts per cell. The low fixed resistance is omitted, or, when used, the voltage must be raised to give the proper charging current. Figures 55 and 56 show the characteristics of the lead-acid and Edison cells when charged by the constant voltage method. It is interesting

to note the rate at which the temperature of the lead cell rises during the first 2 hours of charge. This rapid rise in temperature necessitates watching to see that the safe limits are not exceeded. The contrast between the two types of cells with reference to their temperature changes on charge and discharge is marked. This is shown by the curves.

68. Charging the Nickel-iron-alkaline Cell.—The process of charging the Edison cell is essentially the same as that of the lead-acid cell. There are a few details, however, that differ. The following detailed explanations are abstracted from the booklet of instructions issued by the manufacturing company:

In connecting the battery to the charging circuit always connect the positive terminal of the battery to the positive side of the line, and the negative terminal to the negative side of the line. The positive terminal of the Edison cell is designated by a red bushing around the pole and a plus (+) mark stamped on the top of the cover. The negative terminal is distinguished by a black bushing around the pole and no distinguishing mark on the cover.

Before starting to charge, open the covers of the compartment if the battery is in one. See that the solution is at the proper level, and in charging do not allow the temperature of the solution to exceed 115 deg. Fahr.

The proper length of charge depends upon the extent of the previous discharge. If the battery is totally discharged, recharge at normal rate for the proper number of hours as given in Table VII. If the battery is only partially discharged, recharge at the normal rate for the same fractional interval of time, namely for one-half discharge, one-half the time, etc.

If the extent of the previous discharge is unknown, charge at the normal rate until the voltage per cell remains constant at about 1.8 volts for 30 minutes. When an ampere-hour meter is used, it should be set so that when the meter indicates full charge approximately 25 per cent more electricity has passed than on discharge. When charging at constant rate, it is necessary to adjust the rheostat, or raise the

TABLE VII.—ELECTRICAL DATA FOR EDISON CELLS

Type of cell	Normal charge and discharge, rate in amperes	Ampere-hour capacity, normal rate	Proper level of solution, inches	Hours to charge
A3	22½	112½	½	7
A4	30	150	½	7
A4H	30	150	3	7
A5	37½	187½	½	7
A5H	37½	187½	3	7
A6	45	225	½	7
A6H	45	225	3	7
A8	60	300	½	7
A8H	60	300	3	7
A10	75	375	½	7
A10H	75	375	3	7
A12	90	450	½	7
A12H	90	450	3	7
B1H	3¾	18¾	2¼	7
B2	7½	37½	½	7
B2H	7½	37½	2¼	7
B4	15	75	½	7
B4H	15	75	2¼	7
B6	22½	112½	½	7
B6H	22½	112½	2¼	7
G4	30	100	½	4¾
G5	37½	125	½	4¾
G6	45	150	½	4¾
G7	52½	175	½	4¾
G9	67½	225	½	4¾
G11	82½	275	½	4¾
G14	105	350	½	4¾
G18	135	450	½	4¾
J3	11¼	37½	½	4¾
J5	18¾	62½	½	4¾
J6	22½	75	½	4¾
J7	26¼	87½	½	4¾
J9	33¾	112½	½	4¾
L20	3¾	12½	½	4¾
L30	5⅝	18¾	½	4¾
L40	7½	25	½	4¾
M8	1	4½	½	8
M20	2½	11¼	¾	7
W2t	½	2½	½	7

charging voltage, every half hour or so to keep the current at the proper value. In making these adjustments, it is a good plan to raise the current a few amperes above normal so that it will not drop much below normal before the next adjustment. Edison cells may also be charged by the constant potential method if a suitably adjustable rheostat is available. If this method is used, the rheostat is adjusted so that the initial current is about 50 per cent above normal. As the battery charge increases, its voltage increases, thus automatically decreasing the current. By this method the current will automatically taper until at the end of the charge it will be considerably below normal. The duration of the charge should be the same as for the normal rate.

The Edison cell should be given an overcharge when the electrolyte is renewed. When the battery is discharged at a much lower than normal rate, it is recommended that an overcharge of about two hours' duration at normal rate be given. Although the battery may seldom be completely discharged in service, nevertheless it is advisable to overcharge it occasionally.

Before starting an overcharge, the battery should be completely discharged and the solution brought to the proper level. Tests of solution height should be made before and after overcharge, but not during the charge. The charge should be continued 12 hours for those types of cells for which the normal period is 7 hours and 8 hours for those types for which the normal charging period is 4.75 hours. Repeat this overcharge after 30 days', and again after 60 days' service.

The nickel-iron-alkaline battery may also be charged at high rates for short periods of time, provided the temperature of the electrolyte near the center of the battery does not rise above 115 deg. Fahr. The following table gives rates that may be used for brief intervals, provided the temperature limits are not exceeded:

5 times normal rate for 5 minutes
4 times normal rate for 15 minutes
3 times normal rate for 30 minutes
2 times normal rate for 60 minutes

Frothing at the filler opening is an indication that the excessive charge at the high rate has been carried too far. The charge should be discontinued at once. While low rates of charge do no permanent harm, the best results are obtained if the cells are charged at normal rates. Table VII gives useful data for the maintenance of the Edison storage battery.

RECAPITULATION

1. A storage cell is charged by passing an electric current through the cell against its electromotive force. By electrochemical action the charging current restores the plates to a condition for again delivering current.

2. Direct current only can be used for charging. Alternating current must first be rectified before it can be used for charging.

3. The charging voltage must be higher than the sum of the voltages of the cells that are connected in series. Best results are obtained when the charging voltage at the busbars is about 2 volts per cell for the nickel-iron cell and between 2.3 to 2.7 volts per cell for the lead battery.

4. The two practical methods of charging are the constant current and the modified constant voltage. The constant current method necessitates that the charging rate be kept constant throughout the charge. This necessitates constant adjustment of the control rheostat or voltage.

Charging by the modified constant voltage method is accomplished by connecting the battery to a constant voltage supply through a low fixed resistance. The charging current decreases from a high initial to a low final rate.

5. In charging storage batteries the temperature rises and, hence, temperature readings must be taken regularly. The temperature limit is 45 deg. Cent. (115 deg. Fahr.) for each type of cells.

6. The general rules for charging lead-acid cells may be summarized as follows:

(*a*) *Charge at any time and at any rate if the temperature does not rise above* 115 *deg. Fahr. and if the cells do not gas freely.* The danger in attempting to follow this rule is that the battery cannot be watched carefully enough to insure that the conditions are being fulfilled. Gassing will do no harm at low charging rates, but at high charging rates it may be so violent as to tear off the active material.

(*b*) *Stop the charging current after the specific gravity of electrolyte has become constant in value.* When the specific gravity no longer increases, it is an indication that no more "sulphate" is being converted and further charging simply results in the decomposition of water and evolution of hydrogen and oxygen gases. This is wasteful of electrical energy

and serves no useful purpose. Once every week, or 2 weeks at most, the battery should be charged at low rate until it gasses freely in order to be certain that the weakest cell of the battery is fully charged. After every cell of the battery has been gassing a short time, the charging current should be stopped, provided that the specific gravity of no cell is increasing. This should be determined by three hydrometer readings at one-half hour intervals.

(*c*) *Follow the instructions of the manufacturer of the battery.* The maker of the battery gives directions for its operation. These instructions are intended for the average man and can be followed safely. They may be modified without harm and often with advantage if the operator understands exactly what he is doing. In the case of large and expensive installations, however, the manufacturer may give certain guarantees of performance. If his instructions are not followed, it may result in his release from responsibility for the failure of the battery to fulfill the guarantee.

QUESTIONS

1. Show by diagram how three storage cells connected in series should be connected to a charging circuit. Mark the polarity of the cells and also of the charging circuit.

2. Can cells of different ampere-hour capacities be satisfactorily charged when connected in series? Explain.

3. What quantities determine the current that a given charging electromotive force will send through a series of cells?

4. What kind of current must be used for charging storage batteries?

5. An electromotive force of 100 volts is available for charging 40 cells. What resistance must be placed in series if the charging current is not to exceed 20 amp.? The internal resistance of each cell is 0.015 ohm.

6. Seventy-two cells are to be charged from a 50-volt source. Assuming that the generator has sufficient current carrying capacity, how can the cells be connected so as to be charged together and what must be the rheostat resistance if the current is not to exceed 20 amp. per cell? The internal resistance of each cell is 0.02 ohm.

7. Give two methods of determining the polarity of a circuit.

8. What is the most satisfactory voltage per cell at the busbars for charging lead-acid cells?

9. Explain what is meant by the constant current method of charging.

10. (*a*) Explain what is meant by the constant voltage method of charging.

(*b*) What are the advantages of the constant voltage method?

11. Why does a battery charged by the constant voltage method never reach a dangerous temperature?

12. Under what charging rate will the heat of a cell be less, at the high rate or at the low rate? Explain why.

13. Why must the temperature of a battery be kept below a certain point? What is the limiting temperature?

14. Show by a curve how the temperature of a cell varies with time when charged by the constant voltage method.

15. Show by a curve how the temperature of a cell varies with time when the cell is charged by the constant current method.

16. (*a*) A 225 ampere-hour cell is to be charged 6 hours by the constant voltage method. What fixed resistance must be used if the bus voltage is 2.55 volts per cell?

(*b*) What will be the initial charging current?

17. Given a battery of fifteen 200 ampere-hour cells to be charged for a period of 6 hours at uniform rate. The busbar voltage is 38 volts. Determine the initial charging current for a 5-hour charge and the required fixed resistance. The cells are to be charged by the modified constant voltage system.

18. Explain how the constant voltage method can be made automatic.

19. What is the objection to using a high resistance in the charging circuit for reducing the voltage to the desired value?

20. How can you distinguish the positive from the negative pole of the Edison cell?

21. How can you tell when the Edison cell is fully charged?

22. What is the limited temperature for the Edison cell?

23. Distinguish between the following kinds of charges, bench charge, equalizing charge, conditioning charge, and trickle charge.

CHAPTER VII

CHARGING CIRCUITS AND EQUIPMENT

69. Control Resistances.—A small storage battery may be charged from a direct-current circuit, such as a 110-volt circuit for lighting and power. The positive and negative terminals of the battery are connected respectively to the positive and negative terminals of the circuit. In order to prevent the flow of an excessive current, if the two volt-

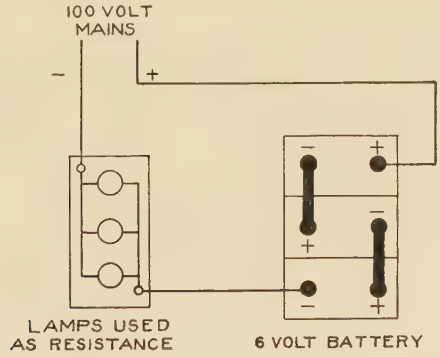


Fig. 57.—Incandescent lamps used as charging resistance.

ages are not approximately equal, it is necessary to have a resistance included in the circuit. Figure 57 shows the connections of a small three-cell battery to a 110-volt lighting circuit for charging, using incandescent lamps for limiting and controlling the current. The ordinary 25-watt tungsten lamp will permit only about 0.2 amp. to flow under these conditions. The old style carbon lamp is more suitable for use as a resistance and is more economical. The 500-watt heater bulbs, such as are commonly used in certain types of luminous radiators, are quite suitable for use as resistances and are probably cheaper than any other

homemade contrivance. Lamps have the advantage that the passage of current is indicated by some degree of illumination.

The carbon lamps differ from the tungsten, or so-called mazda, lamps in their resistance characteristics. The resistance of the plain carbon lamp is approximately constant or decreases with increase in temperature, while the resistance of the mazda lamp increases with increase

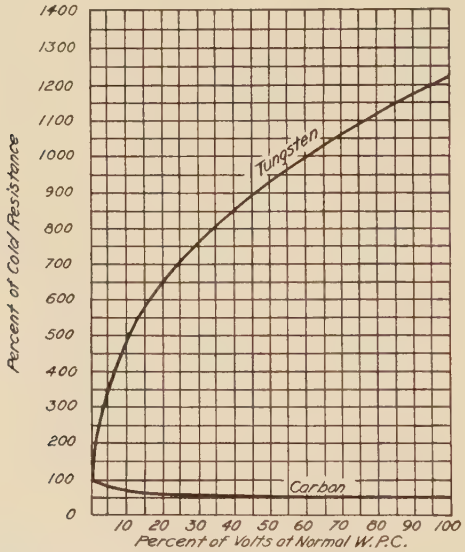


FIG. 58.—Temperature-resistance curves of tungsten and carbon.

in temperature. The temperature is a function of the current flowing, and this in turn depends upon the voltage applied. Since the temperature of the lamp filament is not ordinarily known it is more practical to express the above mentioned characteristics as a relation between voltage and resistance. This is shown in Fig. 58. It will be observed that from 50 to 100 per cent of its rated voltage the change in resistance of the carbon lamp is not great, hence it is comparatively easy to calculate the number of such lamps necessary for a required charging current.

Let W = rated consumption of one lamp in watts
E = rated voltage of lamp at which consumption is W watts
I = current required for charging
R = resistance of each lamp
N = number of lamps required
and E_b = battery voltage.

Then $E - E_b$ = voltage applied to lamps

and $\frac{R}{N}$ = joint resistance of N lamps in parallel;

hence

$$I = \frac{E - E_b}{\frac{R}{N}}$$

and

$$N = \frac{IR}{E - E_b}.$$

But

$$R = \frac{E^2}{W}.$$

Substituting in above equation for N we get,

$$N = \frac{IE^2}{W(E - E_b)}.$$

This expression translated into words means that the number of lamps required for a given current is equal to the product of the required current in amperes by the square of the charging circuit voltage in volts, divided by the product of the watts rating of one lamp by the difference between the applied voltage and battery voltage.

EXAMPLE

Five lead-acid cells are to be charged from a 110-volt circuit. How many 110-volt, 50-watt carbon lamps must be used if the charging current is to be 10 amp.?

SOLUTION

To make the battery voltage as large as possible, and thus reduce the energy loss in the lamps, the storage cells must be connected in series. If each cell has an e.m.f. of 2 volts, then

$$E_b = 2 \times 5 = 10 \text{ volts}$$
$$E = 110 \text{ volts}$$
$$I = 10 \text{ amperes}$$
$$W = 50 \text{ watts}$$

and

$$N = \frac{10 \times 110^2}{50(110 - 10)} = 22 \text{ lamps.}$$

The variation in resistance of the mazda lamp within the operating range of voltage is more marked as is shown by the curves. The voltage resistance curve from 60 to 100 per cent of the rated voltage can, without great error, be considered as a straight line. If R is the rated voltage resistance, then the resistance from 60 to 100 per cent of the rated voltage is given by

$$R_2 = \frac{(E_2 - 0.6E)R}{2E_1} + 0.8R$$

where E_2 is the voltage corresponding to R_2, and E is the rated voltage.

If the lamps are used as a series resistance for charging a storage battery, then $E_2 = E - E_b$ which substituted gives

$$R_2 = \frac{0.4E - E_b}{2E}R + 0.8R.$$

The current through each lamp is

$$I_1 = \frac{E - E_b}{R_2}$$
$$= \frac{E - E_b}{\frac{0.4E - E_b}{2E}R + 0.8R}$$
$$= \frac{2(E - E_b)E}{(0.4E - E_b)R + 1.6ER}$$
$$= \frac{2(E - E_b)E}{(2E - E_b)R}.$$

But as before, W, the rating of lamp in watts, is equal to $\frac{E^2}{R}$, or

$$R = \frac{E^2}{W}$$

which when substituted gives

$$I_1 = \frac{2(E - E_b)W}{(2E - E_b)E} \text{ amp.}$$

The total current is

$$NI_1 = I = \frac{2N(E - E_b)W}{(2E - E_b)E} \qquad (A)$$

and

$$N = \frac{I(2E - E_b)E}{2(E - E_b)W} \qquad (B)$$

By equation (A) one can calculate the charging current that will flow when a given number, N, of lamps are connected in parallel, and by equation (B) the number of lamps for a given charging current can be calculated.

EXAMPLES

1. Fifteen 110-volt, 50-watt mazda lamps are used to charge a battery of six lead-acid cells from a 110-volt circuit. What is the charging current?

SOLUTION

Given
$E = 110$ volts
$E_b = 12$ volts
$W = 50$ watts
$N = 15$

Then
$$I = \frac{2 \times 15(110 - 12)50}{(2 \times 110 - 12)110}$$
$$= 6.4 \text{ amp.}$$

2. What will be the charging current if ten Edison storage cells are charged under the conditions of Example 1?

SOLUTION

All the data are the same except E_b which is $10 \times 1.7 = 17$ volts. Then

$$I = \frac{2 \times 15(110 - 17)50}{(2 \times 110 - 17)110}$$
$$= 6.25 \text{ amp.}$$

3. How many 110-volt, 100-watt mazda lamps are needed to charge a six-cell lead battery at the rate of 10 amp. from a 110-volt circuit?

SOLUTION

Given $E = 110$ volts
$E_b = 2 \times 6 = 12$ volts
$I = 10$ amp.
$W = 100$ watts.

Then $$N = \frac{10(2 \times 110 - 12)110}{2(110 - 12)100}$$
$$= 11.7 \text{ or } 12 \text{ lamps.}$$

In the foregoing examples the internal resistance of the cells has been neglected, and furthermore as the voltage of the cells changes during charge the results are not mathematically exact. Lamps should be used only in emergencies, for their use is a wasteful and expensive process.

FIG. 59.—Carbon charging rheostat.

A type of resistance which is commonly used consists of a number of carbon discs assembled in an insulated tube. The current is passed through this pile of discs from one end to the other. Varying the mechanical pressure upon the pile varies the electrical resistance, the resistance being the lowest for the greatest pressure and, consequently, the current being the highest. A tube 2 in. in diameter and 2 ft. in length will dissipate 900 watts of energy without overheating. Two such tubes mounted on a charging panel are shown in Fig. 59. Other forms of control resistance are shown in Fig. 60.

70. Counter-electromotive Force Cells. –In case it is desired to secure a constant drop in potential with a varying flow of current, counter-electromotive force cells may be used. These are similar to storage cells in appearance, but the plates consist of lead alloy, only, and have no active material. The electrolyte is the same as is used in storage cells. The passage of an electric current through one of these cells is opposed by the electromotive force produced by a very thin film of lead peroxide on the one plate and by the lead of the other, and also by the resistance of the circuit through the electrolyte between the

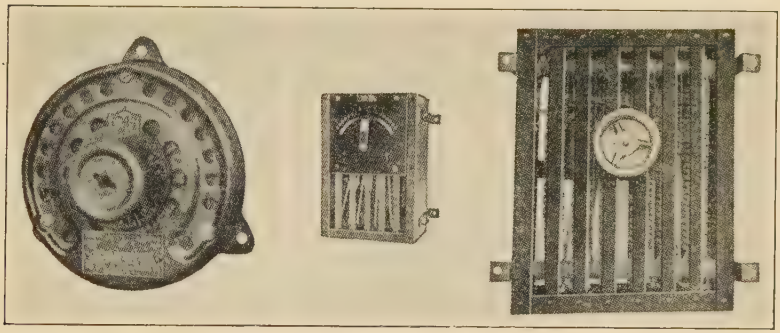


FIG. 60.—Charging rheostats.

plates. This resistance may be made as low as desired by placing the plates close together and by increasing their surface. Consequently, the reduction in voltage is mainly by the counter-electromotive force of the cell. The opposing voltage varies from 2.5 to 3 volts per cell, the latter being for the higher currents.

If a metallic resistance is used, the drop in voltage varies with the current, while with counter-electromotive force cells the drop in voltage is approximately constant. For example, suppose that the voltage of the mains is 120 and it is desired to supply 110 volts to a load of lamps which may vary from zero to twenty amperes. With four counter-electromotive force cells in series with the lamps, the voltage at the lamps would vary from 110 to 108 volts, while with

a metallic resistance of one ohm in series with the lamps, the voltage would vary between 120 and 100 volts.

If a battery is to be charged at constant voltage and the charging voltage is too high for the number of cells, counter-electromotive cells are an ideal means of reducing the excess voltage. It must be understood, however, that the power represented by the product of the amperes and volts across the counter-electromotive force cells is wasted. The counter-electromotive force cell is not reversible on account of its lack of active material.

Discarded plates from worn-out cells are well suited for the elements of counter cells as these are sometimes called. Their installation and operation are no more complicated than for end cells. The switching operation may be more simple as the short-circuiting of the counter cells is of no practical importance. Counter cells require less attention than end cells because they will stand more abuse and do not need to be charged.

71. End Cells.—The terminal voltage of a battery of 60 lead-acid cells varies from 108 volts when discharged to 150 volts when charged; consequently, for use on constant voltage circuits some means must be provided for adjusting the voltage. One of the simplest methods for accomplishing this is to have a certain number of cells so arranged with a switch that they can be disconnected from the circuit as the voltage rises, or connected to the circuit as the voltage falls. For a 60-cell battery, 44 cells may be connected permanently in the circuit and 16 cells so arranged that one after the other may be connected or disconnected as the necessity demands. These cells are called "end cells," and the switch for controlling them is called an "end cell switch." The principles of operation of an end cell switch will be readily understood from Fig. 61 which shows only seven contact points. As shown, the outside terminal of the end cell and the junction points of adjacent cells are connected to "buttons" or contact points 1 to 7 inclusive. These contact points are arranged in a circle at the center of which is pivoted a contact arm.

One side of the load circuit is connected to the shaft on which the arm rotates and the other to one terminal of the battery. As the voltage of the battery drops, the arm is moved counter-clockwise cutting in more cells. To decrease the voltage the arm is moved clockwise, which operation disconnects some cells from the circuit.

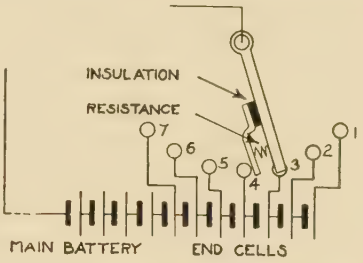


FIG. 61.—Principle of end-cell switch.

It is evident from the figure that if the buttons are close together the sliding contact of the arm will short-circuit the cell whose terminals are connected to two adjacent buttons. On the other hand, if the buttons are separated so far that the contact of the arm cannot touch two at the

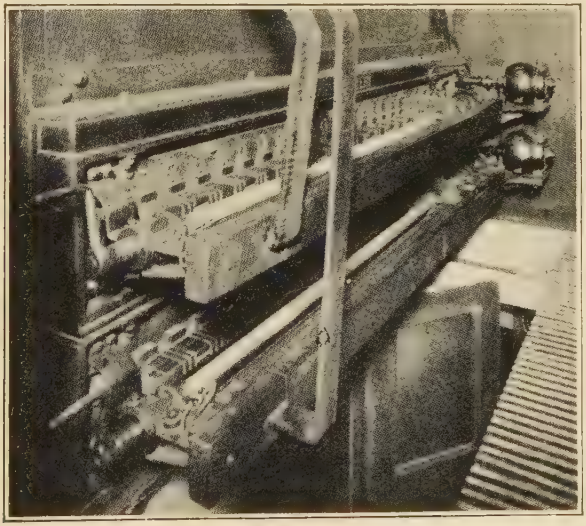


FIG. 62.—Large end-cell switch.

same time, the load circuit will be opened which is likewise undesirable. To obviate both these difficulties, an auxiliary contact is mechanically, but not electrically, connected to the arm. The electrical connection is made

by a low resistance. This resistance is so low that the voltage drop across it, due to the line current, is small, and yet it is high enough so that the current of the short-circuited cell is low.

In practice the smaller end cell switches are mounted on a switchboard and are operated by a hand-wheel. The end-cell switch for large power plant installations has the contact points usually arranged in a row, and a laminated brush is moved across them by a motor-driven screw, Fig. 62.

72. Motor-generator Charging Sets.—Batteries can be charged most economically if the charging voltage is only

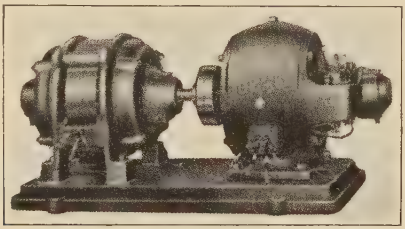


FIG. 63.—Motor-generator set.

slightly higher than the combined electromotive force of the cells that are connected in series to the charging circuit. Under such conditions most of the energy is utilized in converting the active material into a useful condition. In case only alternating current is available, or if the voltage of the commercial d-c. circuit that is available is too high, the most satisfactory converter is a direct-current generator driven by a motor of suitable type. Figure 63 shows an a-c. motor direct connected to a direct-current generator, preferably shunt wound. The set shown is especially designed for charging industrial vehicle batteries from an a-c. source. Generators are designed to develop a voltage of 42 to 78 volts, and a current of such values as to permit charging at the highest efficiency.

If the generator is compound wound and no protective device is used, there is danger of the current from the battery flowing through the generator and driving it as a

motor at abnormally high speed or reversing its polarity. This is due to the fact that the current through the series winding is in a reverse direction when the battery voltage is higher than the voltage of the generator, but the current in the shunt field is in the same direction as before. If the series field under this condition is stronger than the shunt field, the generator polarity is reversed. If the generator is free to revolve, its speed may become dangerously high since the series field tends to weaken the shunt field, and the machine revolves at a higher rate with weaker fields just as any other type of direct-current motor. To protect the generator and battery against reversal of current, reverse-current relays are connected to the circuit. These open the circuit in case the generator voltage is accidentally lowered to such a degree that the battery tends to send a reverse current through the generator. The alternating current motors are usually of the induction type. They are designed for 220 to 440 or 550 volts, 3- or 2-phase 60-cycle circuits. When the supply voltage is direct, the motor is preferably of the shunt type and of somewhat higher rating than the generator.

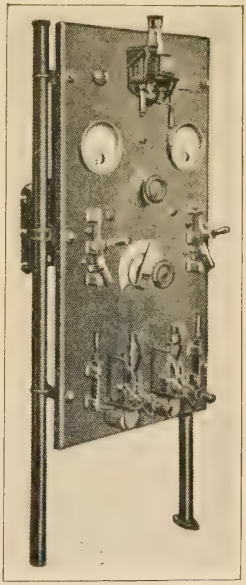


FIG. 64.—Motor-generator switchboard.

The complete equipment for a motor-generator charging set will vary with the particular installation and number of charging circuits desired. A two-circuit battery-charging switchboard specially designed for charging vehicle batteries is shown in Fig. 64. This switchboard is equipped with: one ammeter; one voltmeter; one overload circuit breaker with shunt trip attachment; one generator field rheostat; two ammeter-voltmeter switches; two single-pole underload, shunt trip circuit breakers; two single-pole single-throw lever switches; and one battery-charging

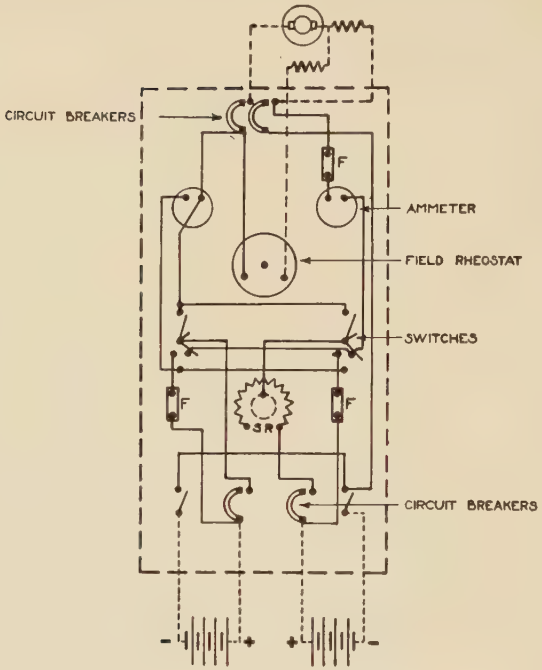


FIG. 65.—Switchboard connections.

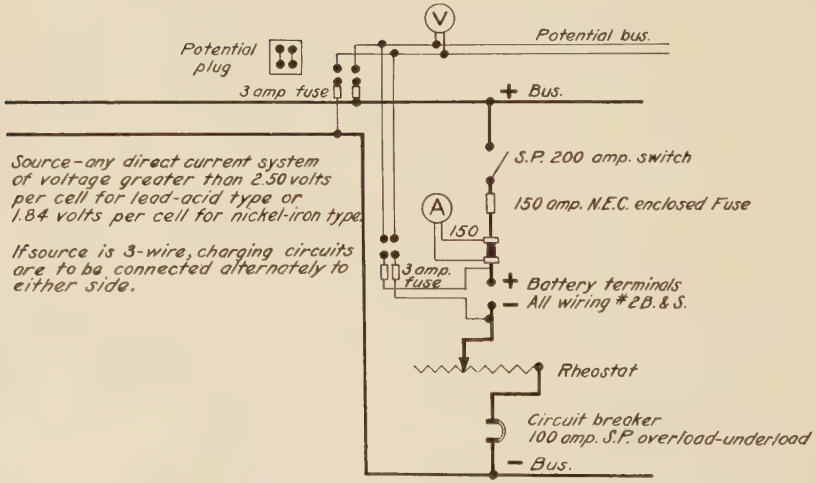

V
Potential bus.
Potential plug
3 amp fuse
+ Bus.
Source—any direct current system of voltage greater than 250 volts per cell for lead-acid type or 1.84 volts per cell for nickel-iron type.
If source is 3-wire, charging circuits are to be connected alternately to either side.
S.P. 200 amp. switch
A
150 amp. N.E.C. enclosed Fuse
150
3 amp. fuse
+ Battery terminals
− All wiring #2 B. & S.
Rheostat
Circuit breaker
100 amp. S.P. overload-underload
− Bus.

FIG. 66.—Suggestive connections for charging panel.

rheostat which is made up of iron grids and mounted on the back of the switchboard. The complete outline of this panel and its connections are shown in Fig. 65. For charging vehicle batteries by the constant current method the switchboard circuit may be conveniently arranged as shown in Fig. 66.

A similar arrangement is suitable for charging by the modified constant voltage method. For a three-wire source of supply the switchboard circuits are shown in Fig. 67.

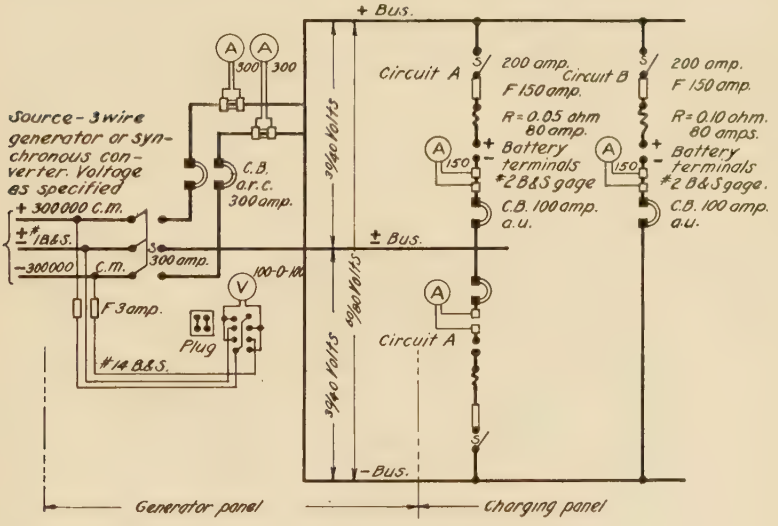


FIG. 67.—Connections of three-wire charging panel.

With a three-wire supply two voltages are available, the one double the other. By using an auxiliary rheostat in place of the fixed resistance, small batteries may be charged from either side by the constant-current method.[1]

73. Charging Equipment for Large Garages.—The type of equipment which finds application in the charging of batteries of large fleets of commercial electric vehicles is composed of a number of unit sections assembled in frames. Each section is 10 in. high and 24 in. wide and is a complete charging unit. Additional sections may be added

[1] *Circular* 92, U. S. Bureau of Standards.

as needed. One of the sections is shown in Fig. 68. A grid-type resistance is employed to regulate the current, and the sliding crosshead by which the resistance is varied

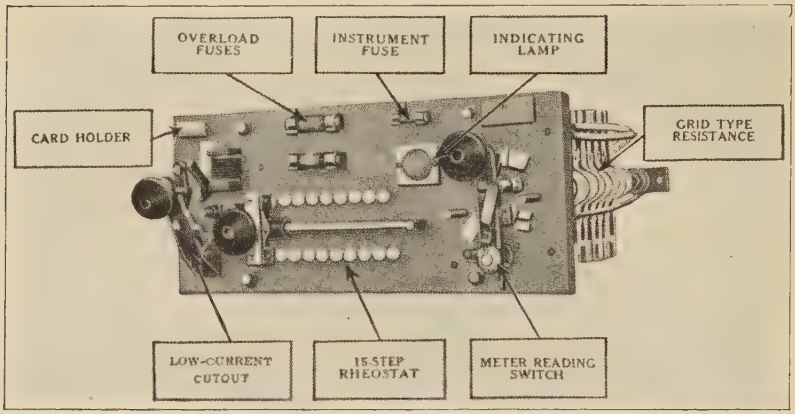


FIG. 68.—Battery charging panel.

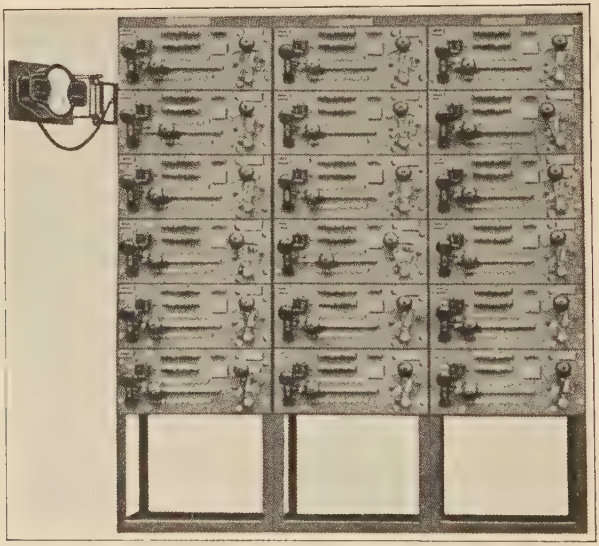


FIG. 69.—Battery charging panels.

is so interlocked with the low current cutout that the latter cannot be closed unless the resistance is all in the circuit.

The reverse-current relay or low-current cutout shown at the left of the panel has a small electromagnet in series

with the charging circuit. This electromagnet holds the underload cutout closed unless the current falls too low, when it releases the switch and the circuit is opened. This prevents the battery from discharging through the generator or through other batteries on the same board if the charging voltage falls too low. The meter-reading switch is provided with three contact points: open, closed, and meter reading. When it is in the open position, the circuit to the battery is interrupted. The circuit to the battery is completed when the switch is moved to the closed position. By moving the switch still further, against the action of the spring, both the current and the voltage may be read on the duplex meter, Fig. 69. The current for a large equipment of this kind is obtained either from a central station supply or from a direct-current generator driven by any available source of power.

74. Rectifiers for Charging Storage Batteries.—In many instances where only alternating current is available the expense of the installation of a motor-generator set and switchboard for charging purposes is not justified, and other means must be provided. Since only direct current is suitable for charging, the alternating current must be changed to direct current before it is passed through the battery. This changing of the alternating current to direct current is known as rectification, and the apparatus or instrument by means of which the conversion is made is known as a rectifier.

An alternating current is one that is constantly changing in intensity and reverses its direction of flow periodically. Graphically the fluctuations of an alternating current with time may be represented by the wave of Fig. 70*a* which is drawn for a 25-cycle current. In this figure the distance horizontally from the point marked *o* represents elapsed time after closing the circuit. The distance from this line to the wave represents the intensity and direction of the current flow at any particular instant. Thus at the instant of closing the circuit the current is zero, $\frac{1}{200}$ sec. later the value of the current is represented by the line *ab* in the

positive direction. This means that in Fig. 70*b* the current at this instant is flowing from *A* to *B*. After an interval of $\frac{1}{100}$ sec. the current is represented by the line *cd* still in the positive direction. After an interval of $\frac{1}{50}$ sec. the current is again zero, and during the interval from $\frac{1}{50}$ to $\frac{1}{25}$ sec. the current passes through a similar set of values but in a reverse direction, namely from *B*

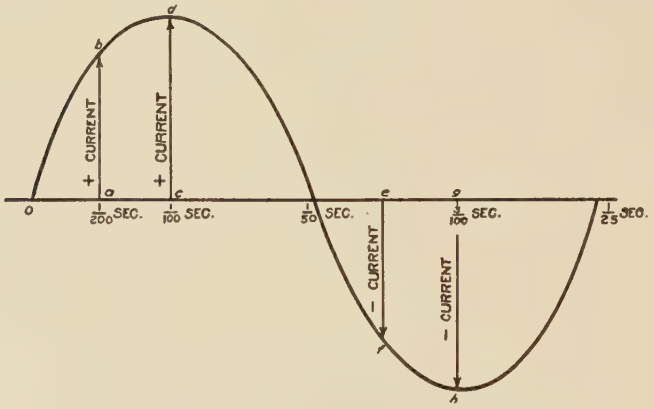


FIG. 70*a*.—An alternating-current curve.

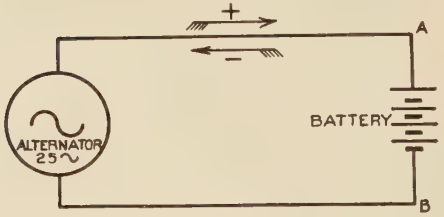


FIG. 70*b*.

to *A*, Fig. 70*b*. Thus the current is shown as constantly varying or changing in intensity, and periodically, once every $\frac{1}{50}$ sec., reversing its direction of flow. In $\frac{1}{25}$ sec. the current has passed through a complete cycle of values and is entering upon its second set of values which is an exact repetition of the first set. It is evident that if the connections shown in Fig. 70*b* are used, the battery will be charged for the first 0.02 sec. and discharged for the succeeding 0.02 sec. If, however, the connections at

A and B are reversed every time the current in the circuit reverses, the current can be made to flow through the battery continuously in the same direcion. Again, if the lower half of the current wave is suppressed, the flow of current through the battery will be in the same direction although it will not be continuous. The current will flow for 0.02 sec. and for the succeeding 0.02 sec. there will be no current.

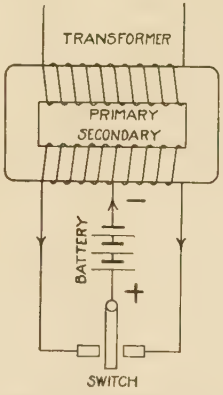


FIG. 71.—Principle of vibrating rectifier.

Any device that will interchange the connections every time the direction of current flow reverses, or opens the circuit when the current flows in the negative direction and closes it when it is in the positive direction, is a rectifier. Rectifiers are of many kinds, the most common one being the commutator on a direct-current generator. The term rectifier is seldom, however, applied to the commutator which is an integral part of the generator, but to devices that are distinct and separate from the generating equipment. These may be classed under four separate heads:

(a) Mechanical rectifiers
(b) Mercury vapor rectifier
(c) Electrolytic rectifiers
(d) Electron rectifiers.

(a) *Mechanical Rectifiers.*—As the name suggests, these are devices that mechanically interchange the connections as explained above. The exact operation of such a device will be readily understood from Fig. 71. In this figure the primary coil of an alternating-current transformer is shown connected to the mains and the secondary coil to two parts of a vibrating switch. The battery to be charged is connected from a terminal at the center of the secondary coil to the hinge of the vibrating switch. If we imagine the switch to be moved back and forth with sufficient rapidity and keep it accurately timed with the alternations

of the circuit, a continuous current will flow in the proper direction through the battery. The switch must be to the left at the same time that the left-hand terminal of the transformer is positive. A current will then flow from the left terminal through the switch, the battery, and the left-half of the transformer secondary winding. At this time the right-half of the secondary winding is carrying no current.

Just as the polarity of the alternating mains is reversing, the switch must be thrown to the right. The right terminal of the secondary is then positive and the current flows from it through the switch, the battery, and the right-half of the secondary winding. If the current has a frequency of 60 cycles, it changes direction 120 times a second, and the switch must be moved from left to right and from right to left at this rate.

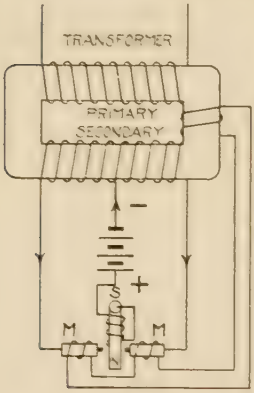


FIG. 72.—Vibrating rectifier.

In order that the switch may vibrate at exactly the same frequency as the alternating current, it must be operated by a current derived from the same source. How this is accomplished is shown in Fig. 72. A small current may be derived from a special coil on the transformer and used to excite a pair of small electromagnets shown at *M*. The polarity of these magnets reverses with the reversal of the alternating current. If, then, the switch be polarized magnetically as shown, it will be attracted and repelled by the reversals of polarity of the magnets *M*. This will cause the switch to move backwards and forwards with each reversal of current. If a coil of wire be wound around the switch blade *N-S* as shown in Fig. 72, so that the rectified current flowing through the battery passes through this coil, the magnet becomes an electromagnet of constant polarity and the necessity for making it a permanent magnet is obviated. This simple scheme has

been developed into a satisfactory device although many difficulties had to be overcome.

(*b*) *Mercury Vapor Rectifier.*—In many respects the most useful device for converting an alternating current into direct current for charging storage batteries is the mercury arc rectifier. The essential features of such a rectifier are a bulb, Fig. 73, an auto transformer, reactance, and dial switches for raising and lowering the voltage. The rectifying is performed by a highly evacuated, hermetically

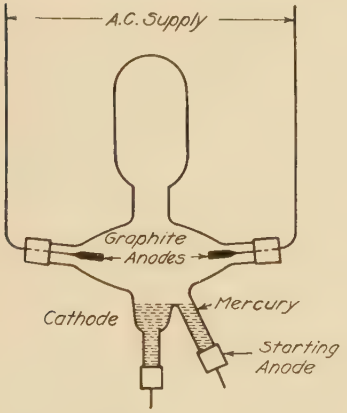


FIG. 73.—Principle of mercury rectifier.

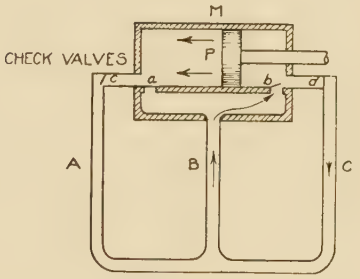


FIG. 74.—Analogy for mercury rectifier.

sealed glass bulb filled with mercury vapor and provided with four electrodes. Two of these are of graphite or other suitable material and the other two of mercury. The a-c. supply circuit is connected to the two upper electrodes, and as the current enters by way of these they are called anodes. The current leaves by way of the lower larger mercury electrode, and hence this is known as the cathode. The small mercury electrode is used for starting as will be explained later.

The electrical operation of the rectifier will perhaps be more readily grasped if a mechanical analogue is first considered. In Fig. 74 is shown a piston *P* which can be moved back and forth in the cylinder *M*. If this cylinder and all connecting chambers and pipes are filled with water, then the forward and backward motion of the piston will

cause a circulation of the water through the pipes as indicated by the arrows. The water ahead of the piston is forced through valve *c* and up through pipe *B*, thence through valve *b* to the right side of the piston. When the piston is moved to the right, valves *c* and *b* are closed and valves *a* and *d* are opened. The water is then forced down pipe *C* and again up pipe *B* to the left end of the cylinder. No matter in which direction the piston is moving the flow of water through *B* is continuously in one direction. With reference to the cylinder, the water surges from one side to the other, but with reference to pipe *B* the flow of water is unidirectional. This unidirectional flow has been secured by the agency of the valves *a*, *b*, *c*, *d*, and of the pipes *A*, *B*, *C*. In an analogous manner the alternating current that is supplied to the two graphite electrodes is converted into direct current which flows out continuously at the large mercury cathode.

The connections of the bulb for battery charging are shown in Fig. 75. The a-c. supply is connected through the auto transformer to the two anodes *A* and *B*, while the battery is connected between the mercury cathode *C* and the middle of the transformer winding. Since all the air has been removed from the bulb, it is filled with a highly rarefied mercury vapor. This mercury vapor possesses the characteristic property of conducting an electric current from the solid anode but not in the reverse direction nor from one graphite electrode to the other. As the solid or graphite electrodes are alternately positive and negative the current flows from one of them for one half cycle and from the other for the other half cycle. Through the battery the current flows continuously from *C* to *N*. The anodes of the bulb thus perform a function similar to that of the valves *c* and *d*, Fig. 74; namely, permitting the current to pass into the mercury vapor but preventing its passage from the mercury vapor to the anodes.

The above explanation applies after the bulb has started to operate. The bulb cannot be made to operate by merely closing the circuit. There is a high resistance at the

surface of the mercury which must first be broken down before the current will flow. This resistance acts like an insulating film over the whole surface of the mercury. To break down this resistance is the function of the small mercury electrode *S* which is connected to one side of the line through a high resistance as shown in Fig. 75. To start operating, the bulb is tilted until the mercury in the two

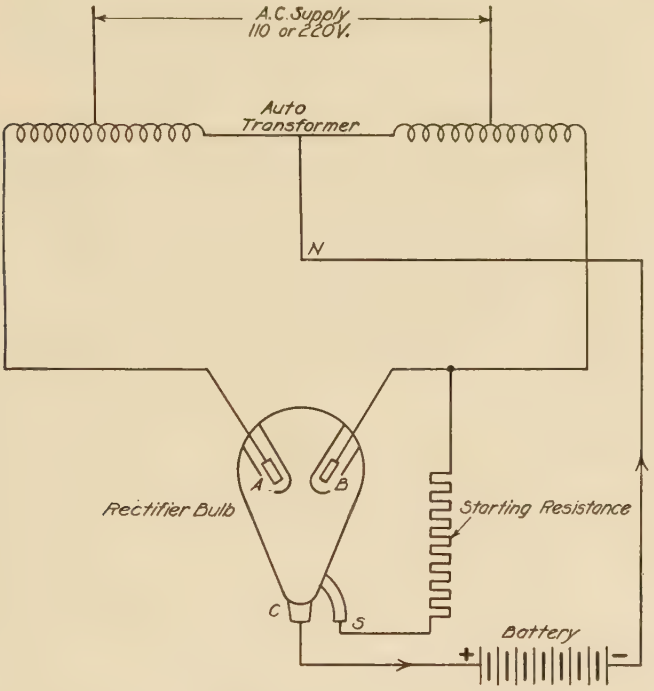


FIG. 75.—Auto-transformer and mercury rectifier.

electrodes *C* and *S* runs together. This makes a metallic connection between the two sides of the line, permitting the flow of current. As the bulb is tipped back to normal position the mercury separates and a spark occurs at the point of separation. If at this instant the small mercury electrode is an anode, then the current will continue to flow from the graphite anode to which the starting anode is connected for the remaining portion of the half cycle; and when the polarity of the graphite electrodes is reversed, the

current will flow from the other anode to the mercury cathode. When the current is once established, the rectifier will continue to operate as long as the current supply is uninterrupted and the direct current does not fall below

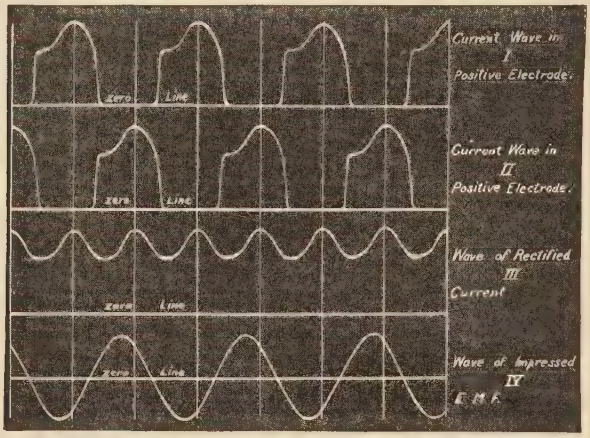


FIG. 76.—A-c. current rectified by mercury rectifier.

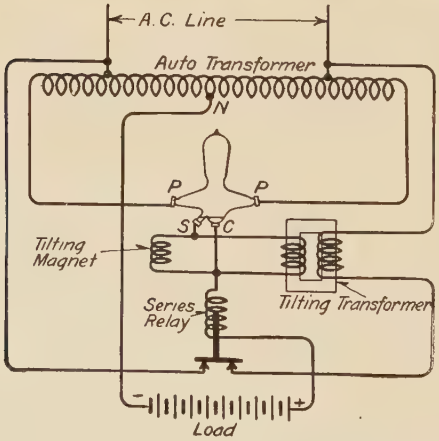


FIG. 77.—Connections for mercury rectifier with tilting transformer.

the minimum required for the arc. If, however, at the instant of the occurrence of the spark, the small mercury electrode is the cathode, the current will cease as soon as the circuit is broken and the bulb must be retilted.

The fact that the high-resistance film is remade at the instant the current ceases necessitates an arrangement that will prolong the current from one electrode until the current has had time to become established from the other electrode. This is accomplished by inserting a reactance in the direct-current circuit or in the transformer. This causes a prolongation of the current waves from the two electrodes so that they overlap. The pulsations of current

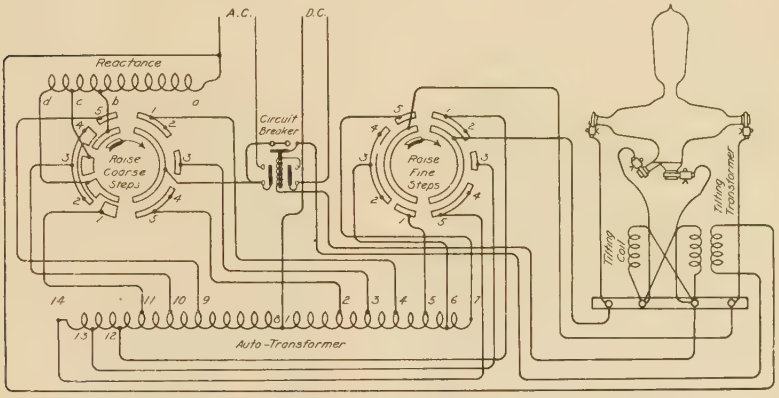


FIG. 78.—Connections for 30-amp. mercury rectifier.

from each anode and their overlapping are shown in Fig. 76. Loops I and II are current pulsations from each anode, and as shown the current from one does not become zero until the current from the other anode has reached a value sufficiently high to maintain the current. The combination of these loops gives a current through the battery of the form shown by III. While the rectified current has ripples, it, nevertheless, is direct; that is, flows continuously in one direction. To measure its average value correctly a permanent magnet type of ammeter should be used.

It was stated above that the rectifier cannot be started by merely connecting the anodes to the supply circuit. This is correct if the statement applies merely to the electrical or rectifying operation, but as shown in Fig. 77 the circuits can be arranged so as to make the tilting operations automatic.

To control the current and to adjust the rectifier to different line voltages and different number of cells, taps are provided on the auto transformer. From these taps, connections are made to sliding contacts by means of which the connections to the bulb or alternating-current line may be changed. In this way adjustments can be made without the losses that would result from the use of a resistance. A complete diagram of connections for a 30-amp. rectifier is shown in Fig. 78, and the complete rectifier is shown in Figs. 79 and 80.

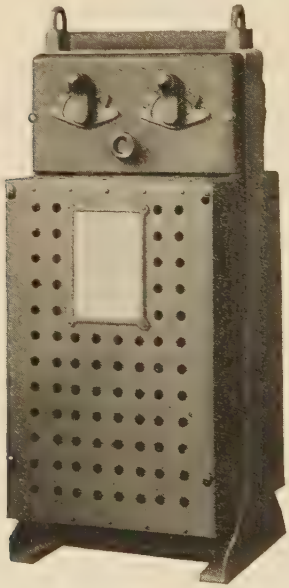


Fig. 79.

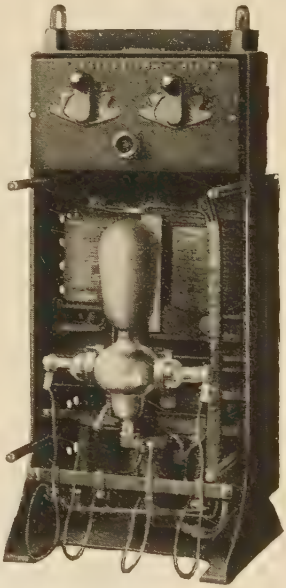


Fig. 80.

Two views of a mercury rectifier.

(c) *Electrolytic Rectifiers.*—The electrolytic rectifier is in principle much the same as the mercury vapor rectifier. In the mercury rectifier, current is conveyed by the vapor from the solid cathode to the mercury anode. An electrolytic cell having aluminum and lead for the electrodes and sodium ammonium phosphate for the electrolyte will similarly permit the current to flow from the lead plate to the aluminum plate but not in the reverse direction unless

the applied voltage is above a certain critical value. The aluminum plate becomes covered with a thin film of

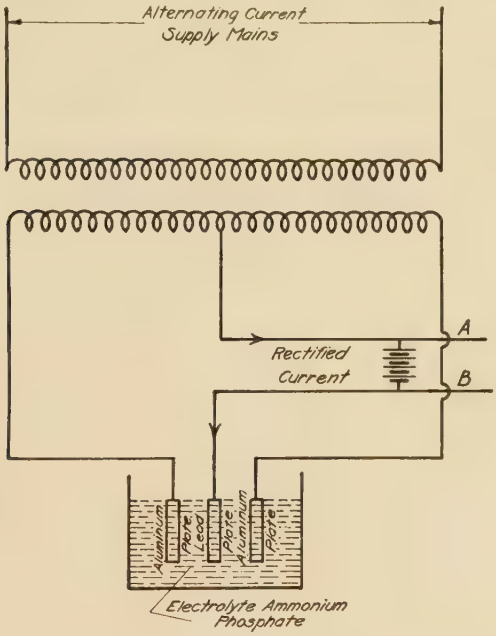


FIG. 81.—Electrolytic rectifier.

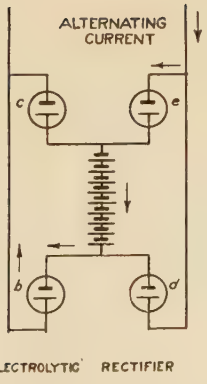


FIG. 82.—Connections for rectifying both loops of an alternating current.

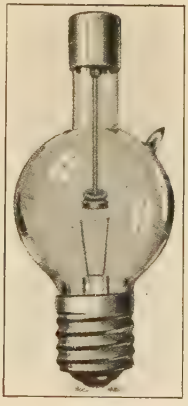


FIG. 83.—A tungar bulb.

some oxide which almost instantly insulates it against the passage of current from the plate but conducts it to the

plate rather readily. This insulating property is analogous to the action of a check valve and gives the name to the device. For rectifying both loops of the alternating current, the cell is constructed as shown in Fig. 81. The lead plate is placed between two aluminum plates and the battery to be charged is connected to this plate and to the middle point of an auto transformer or secondary winding of a transformer. Four of these cells and the battery to be charged

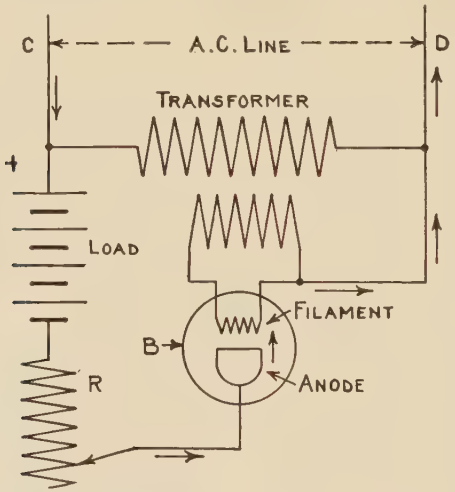


FIG. 84.—Principle of electron rectifier.

may be connected to a source of alternating current as shown in Fig. 82. During half of the cycle the current passes through the circuit consisting of valve *e*, the battery, and valve *b*. During the next half cycle, the circuit is through valve *c*, the battery, and valve *d*. The current may be controlled by a resistance in either the alternating- or the direct-current side. This type of rectifier is practical but neither durable nor efficient. The efficiency is seldom over 60 per cent.

(*d*) *Electron Rectifiers.*—Like the mercury and electrolytic rectifiers the electron rectifier makes use of the "check valve" principle. The application of this principle in this case is through the agency of two electrodes; one a hot

tungsten cathode, the other a graphite anode and an inert gas, argon. The trade name Tungar is composed of the combination of the first syllables of tungsten and argon.

The rectifier resembles a large incandescent lamp with three terminals, Fig. 83, in which the cathode is shown as

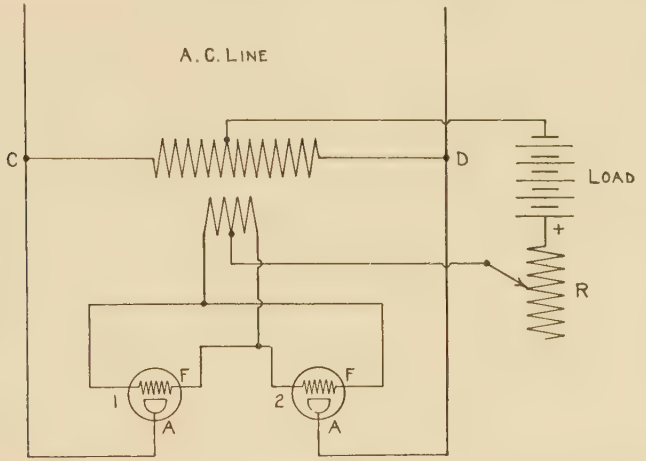


FIG. 85.—Connections of two electron bulbs for rectifying both loops of the alternating current.

a coiled filament and the anode as a cup or button above the filament. When the filament is heated red hot and a difference of potential exists between the anode and filament,

A B

FIG. 86A-B.—Westinghouse electron rectifier.

an electric current will flow from the anode to the filament inside the bulb, but not in the reverse direction. If an alternating e.m.f. be impressed across the graphite but-

ton and the tungsten filament, a current will flow only when the graphite button is positive. When the e.m.f. reverses, no current flows and thus the negative half waves are suppressed. This operation is further illustrated in Fig. 84 in which the circle, *B*, represents the bulb. The filament is heated by an alternating current from the low voltage side of a transformer whose primary circuit is connected directly across the a-c. line. The diagram represents the conditions when the terminal *C* is positive. At this instant the current flows through the battery in the

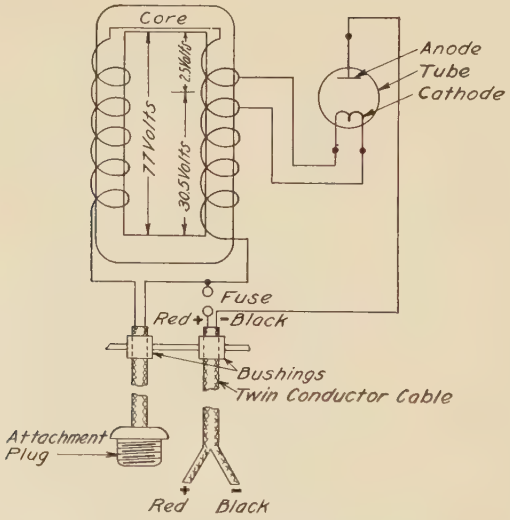


FIG. 87.

direction indicated by the arrows. When the alternating e.m.f. reverses and *D* becomes positive, the flow of current ceases. When only one bulb is used, the charging current is of the form shown in Fig. 90, and its charging value is given by a permanent magnet type of ammeter. Devices which rectify by suppressing one-half of the current wave are known as half-wave rectifiers.

More efficient and rapid charging can be obtained by connecting two bulbs to the circuit as shown in Fig. 85. When *C* is positive, bulb 1 transmits the current, and when *D* is positive, bulb 2 transmits the current. In this

case both half-waves are used, and the resulting current is a pulsating direct current which may be smoothed out by a reactance in the battery circuit. This is unnecessary, however, in ordinary battery charging. Figures 84 and 85 show a variable resistance R for controlling the current. Since this method of current control is wasteful of energy, in commercial rectifier outfits the rheostat is omitted and the current is controlled entirely by means of a compensator with which is combined the filament transformer and reactance, Fig. 86.

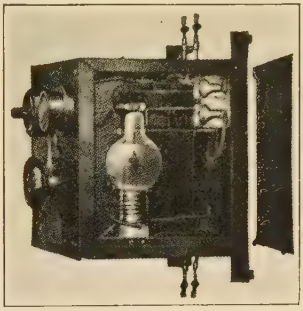


FIG. 88.—A General Electric electron rectifier.

These rectifiers are manufactured by the Westinghouse and the General Electric companies in three styles, all of the half-wave type with different current and voltage

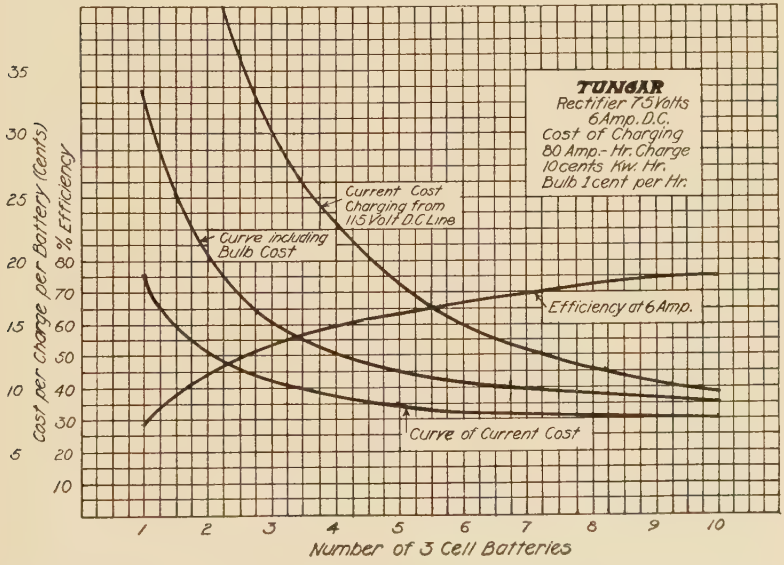


FIG. 89.

capacities—one 2-amp. and two 6-amp. rectifiers. All three types are for 115-volt, 60-cycle circuits. The 2 amp.

unit will charge three cells at 2 amp., six cells at about 1 amp., and eight cells at about 0.75 amp. Complete connections for a G. E. 2-amp. rectifier are shown in Fig. 87. The 6-amp. rectifiers are made for two ranges of voltage on the d-c. side, 7.5 to 15, and 7.5 to 75 volts, respectively. The first is suitable for charging either three or six cells of a lead battery at 6 amp., while the latter will charge from three to thirty lead cells in series at 1 to 6 amp. A 6-amp. unit is shown in Fig. 88.

The efficiency of these rectifiers compares favorably with other reliable devices of equal capacities. These facts are shown by curves of Fig. 89.

75. Charging Value of Rectified Current.—The measurement of a half-wave current involves principles that

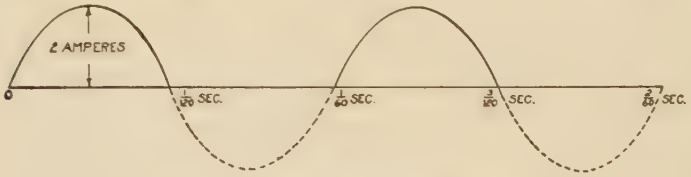


Fig. 90.—A rectified alternating current.

need a more complete explanation. As indicated in Fig. 90, if the dotted half-wave is suppressed, the charging current is represented by the upper half-wave. If the frequency of the alternating current is 60, then for $\frac{1}{120}$ sec. the battery is charged, and for the next $\frac{1}{120}$ sec. no current flows through the battery. Assuming a sinusoidal current wave, such as is shown, the average charging current for a whole cycle is only 0.318 of the maximum current. If the maximum current is 2 amp. as shown, the average charging current is only 0.636 amp. This is the current that an ordinary polarized or permanent magnet type of ammeter, such as is commonly used on d-c. circuits, indicates. The electrolytic effect of this current is the same as that of 0.636 amp. flowing continuously. It is important to note that an ammeter such as is used on an a-c. circuit—a hot-wire meter, or one

based on the electrodynamic principle—will read 0.707 amp. when a current fluctuating as shown in the figure is passed through it. This is known as the effective value in distinction from the average value. It is, consequently, important that the proper type of ammeter be used if the charging current is to be correctly measured.

Another effect of a pulsating current that must be considered is heating.

A constant current of 2 amp. flowing for half of the time has the same effect in charging a storage battery as a current of 1 amp. which flows continuously, but its heating effect is greater. For example, a current of 2 amp. flowing through a resistance of 10 ohms for half-second intervals wastes 20 watts, whereas a current of 1 amp. flowing continuously wastes only 10 watts. An interrupted charging current whose average value is equal to that of a continuous current will heat the battery at a higher rate than the continuous current.

RECAPITULATION

1. For charging storage cells from circuits whose voltage is higher than the combined voltage of the cells, some form of controlling resistance, or counter-electromotive force cells, must be used to reduce the voltage to the desired value. The controlling resistance may be iron wire, grids, lamps, or heater bulbs. The use of controlling resistances should be avoided as much as possible since the energy spent in heating these resistances is all wasted.

2. Counter-electromotive force cells consist of lead plates from which the active material has been removed, immersed in a sulphuric acid electrolyte of the same density as used in the lead-acid cells. When used for reducing voltage to the desired value, they are equivalent to the same number of storage cells connected to the circuit.

3. By end cells is meant the cells that are so arranged that one after another can be connected or disconnected from the line circuit as the necessity demands.

4. An end-cell switch is the device by means of which end cells are connected or disconnected from the circuit.

5. In case only alternating current is available or if the voltage of the supply d-c. circuit is high, which is infrequently the case, the most satisfactory convertor is a direct-current generator driven by a motor of suitable type. This combination of motor and generator is commonly called a motor-generator set. The d-c. motor of such a set is

usually shunt wound while the generator is flat compound wound. The a-c. motor of such a set is usually of the induction type.

6. To prevent the flow of current from a battery through the charging equipment, in case the charging voltage should fall below that of the battery, a device is usually inserted in the circuit which opens it when the current is reversed. Such a device is called a reverse-current relay or low-current cut-out.

7. An apparatus or instrument by means of which alternating current is converted into direct current is known as a rectifier. Rectifiers for charging storage batteries are commonly of the four following types:

(*a*) Mechanical
(*b*) Mercury vapor
(*c*) Electrolytic
(*d*) Electron.

QUESTIONS

1. What is meant by controlling resistances and when must they be used?

2. What objections are there to the use of resistances or lamps in charging circuits?

3. Ten lead-acid cells are to be charged from a 110-volt d-c. circuit. How many 110-volt, 100-watt carbon lamps must be used if the charging current is not to exceed 15 amp.?

4. How many 100-watt mazda lamps must be used for charging ten lead-acid cells if all the conditions are the same as in Question 3?

5. Ten 100-watt, 110-volt mazda lamps are used as a controlling resistance for charging a battery of six Edison cells. What is the charging current?

6. (*a*) What effect does pressure have upon the resistance of a pile of carbon plates?

(*b*) Why is such a set of plates a very satisfactory controlling resistance?

7. What is meant by counter-electromotive force cells? How much power is wasted if five such cells are used, the electromotive force of each cell being 2.2 volts and the charging current 10 amp.?

8. What are end cells?

9. Show by diagram and explain the operation of an end-cell switch.

10. How is the end-cell switch constructed so as to prevent the short-circuiting of any cell and open-circuiting the main circuit?

11. How is the charging equipment protected from the discharging of a storage battery through it?

12. Enumerate the essential switchboard equipment for a two-circuit motor-generator charging set.

13. Diagram the circuit of a switchboard for charging by the modified constant voltage method from a three-wire source of supply.

14. (*a*) Can an alternating current be used for charging a storage battery?

(*b*) What is meant by a rectifier?

15. (*a*) Explain briefly the operation of the mechanical rectifier.

(*b*) Show by diagram how it is connected to a circuit including the battery.

16. (*a*) Explain briefly the mercury arc rectifier.

(*b*) Show by diagram how a mercury arc rectifier is connected to an a-c. circuit and battery.

17. (*a*) What characteristic of the aluminum cell makes it possible to use such a cell as a rectifier?

(*b*) Show by diagram how an aluminum cell may be used for rectifying an alternating current.

18. (*a*) Explain briefly the electron rectifier.

(*b*) Show by diagram how it may be connected to a circuit and battery.

19. How does the efficiency of the electron rectifier compare with other devices of equal capacity?

20. Show by diagram how a two-bulb rectifier is connected to a circuit so that both half-waves are utilized in charging.

CHAPTER VIII

TESTING

76. General.—In order to know the serviceable condition of a storage battery, it is necessary to make certain tests. Some of these tests should be made at regular intervals while others need be made only occasionally, or as the necessity for them is indicated by some symptom. The more common tests are those for ampere-hour capacity, watt-hour capacity, temperature, specific gravity, voltage, and relative charge on the negative and positive plates of a cell.

77. Test for Ampere-hour Capacity.—As already pointed out the relative ampere-hour capacity of a storage cell depends upon at least five factors; namely, specific gravity of electrolyte, temperature, rate of charge and discharge, type of plate, and previous treatment. The influence of these factors has been discussed. The normal or absolute capacity, of course, depends upon the amount of active material on the plates and the number of such plates per cell. Since so many factors affect the ampere-hour capacity and efficiency of a storage cell, it is evident that if a comparison of different cells is to have any meaning their capacities must be determined under like conditions, especially with reference to rate and duration of discharge, and final or end voltage. The normal rate of discharge is specified by the manufacturer, and for certain types of stationary lead-acid batteries the duration of discharge is arbitrarily fixed at 8 hours, and for vehicle batteries at 5 or 6 hours.

To determine the ampere-hour capacity, the battery is discharged through a suitable resistance at the normal rate until the voltage has dropped to 1.70 volts for the lead-

acid cell and 0.90 volt for the nickel-iron cell. The voltage is measured by a voltmeter and the current by an ammeter which are connected to the circuit as shown in Fig. 91. The voltmeter, if permanently connected, should have a high resistance, as the current that passes through it is not indicated on the ammeter. The carbon rheostat is perhaps the simplest and best device for controlling the current. As the pressure of the battery falls on discharge, the rheostat will have to be adjusted occasionally to maintain the current constant. If the ammeter is used to measure the

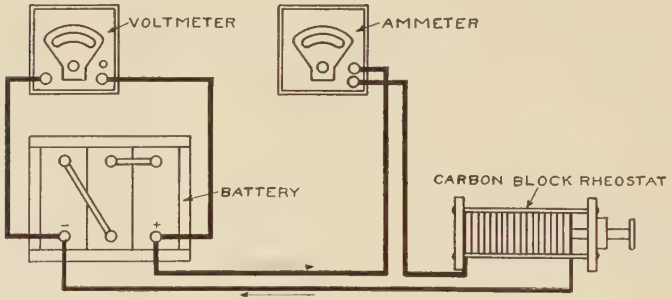


FIG. 91.—Connections for discharge test.

discharge current, the time of beginning and ending will have to be noted accurately. The ampere-hour output is, then, the product of the current in amperes by the duration of discharge in hours.

The accuracy of the result may be somewhat increased if an accurately calibrated ampere-hour meter is connected in series with the ammeter. The difference between the initial and final readings of the ampere-hour meter gives the ampere-hours discharged. The result is likely to be more accurate because the ampere-hour meter automatically corrects for any fluctuations of current that inevitably take place.

78. Test for Ampere-hour Efficiency.—The connections for determining the ampere-hour efficiency are indicated in Fig. 92. From the readings of the ampere-hour meter the ampere-hours required to charge the battery are readily

obtained. The generator is disconnected and the battery is discharged as in the test for ampere-hour capacity. The ampere-hour efficiency is, then, the ratio of the ampere-hours output to the ampere-hours input. If the ampere-hour meter is used for the two tests, the ampere-hour efficiency is obtained at once from the ratio of the meter readings on charge and discharge.

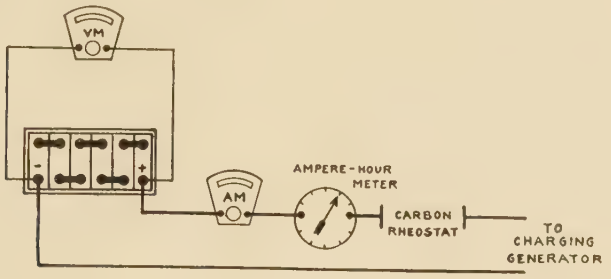


FIG. 92.

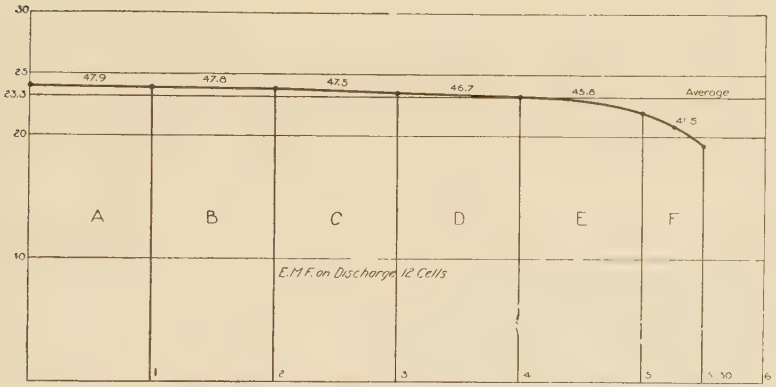


FIG. 93.

79. Test for Watt-hour Capacity and Efficiency.—The watt-hour capacity is equal to the ampere-hour capacity multiplied by the average voltage. To determine the watt-hour capacity, the ampere-hour capacity is first determined and this is multiplied by the average voltage of the battery during the period of discharge. This average voltage is obtained by plotting the voltage readings against time as shown in Fig. 93, and averaging their values as

follows: Divide the area under the voltage curve by vertical lines into a convenient number of sections and read the height of each section at the middle. The area of each section is the product of the base by this height, and the total area is the sum of the areas thus obtained.

The average height of the curve is equal to the area under it divided by its horizontal length. This area may be expressed in any units, provided the quotient of the area divided by the base is multiplied by the voltage per unit vertical scale.

In the figure, the area is shown divided into six sections by vertical lines at the hour intervals and at 5:30. The average height of each section except the last is read at the half hour interval. This average height multiplied by the base gives the area in the units of the horizontal and vertical scale:

Section	Area
A	$47.9 \times 20 = 958$
B	$47.8 \times 20 = 956$
C	$47.5 \times 20 = 950$
D	$46.7 \times 20 = 934$
E	$45.8 \times 20 = 916$
F	$41.5 \times 10 = 415$
Total	5,129

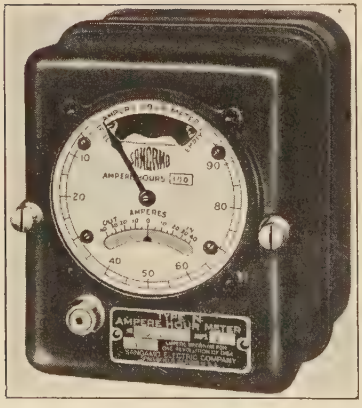


Fig. 94.—Ampere-hour meter.

The base is 110 units long; hence, the average height = 5,129 ÷ 110 = 45.7 units. The vertical scale is 1 division = 0.5 volt; therefore, the average voltage is 45.7 × 0.5 = 22.85 volts.

The smaller the sections and the greater the vertical scale the more accurate will be the result. With a planimeter, the area can be obtained still more accurately.

Having obtained the average voltage, the watt-hour

output is the product of the ampere-hour output by the average voltage. The ampere-hour current is most readily obtained by means of an ampere-hour meter, Fig. 94.

EXAMPLES

1. What is the watt-hour output per cell for the 12-cell battery whose voltage curve is given in Fig. 52, the ampere-hour output being 225?

SOLUTION

The average voltage per cell is $22.85 \div 12 = 1.9$.

The energy output equals $1.9 \times 225 = 427.5$ watt-hours.

The watt-hour efficiency is the ratio of the watt-hours output to the watt-hours input. The average voltage on charge may be obtained by the method described above, and the ampere-hours input by means of the ampere-hour meter.

2. The average voltage per cell on charge is 2.28 volts while the cell is charged at the constant rate of 43 amp. for 6 hours and 18 amp. for 2 hours. Find the watt-hour input.

SOLUTION

The ampere-hour input is $43 \times 6 + 18 \times 2 = 294$ ampere-hours.

The watt-hour input is $294 \times 2.28 = 670.32$ watt-hours.

3. What is the energy efficiency of the cell of Example 2 if the watt-hour output is 427.5 watt-hours?

SOLUTION

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$= \frac{427.5}{670.32} = 0.637$$

or 63.7 per cent.

For a battery of several cells the watt-hour output and input are most conveniently measured by a commutator-type watt-hour meter. This in brief is an instrument consisting of a voltmeter and an ampere-hour element combined. The registration is thus proportional to the product of ampere-hours and volts. Watt-hour meters are, however, seldom made for less than 100 volts, and furthermore the discharge rate of large storage cells is too high for the current coils of the watt-hour meter unless

they are shunted. Such an instrument with cover removed is shown in Fig. 95.

If the watt-hour meter is first used to register the watt-hour input, the connections of the current coils must be reversed before it can be used to register the watt-hour out-

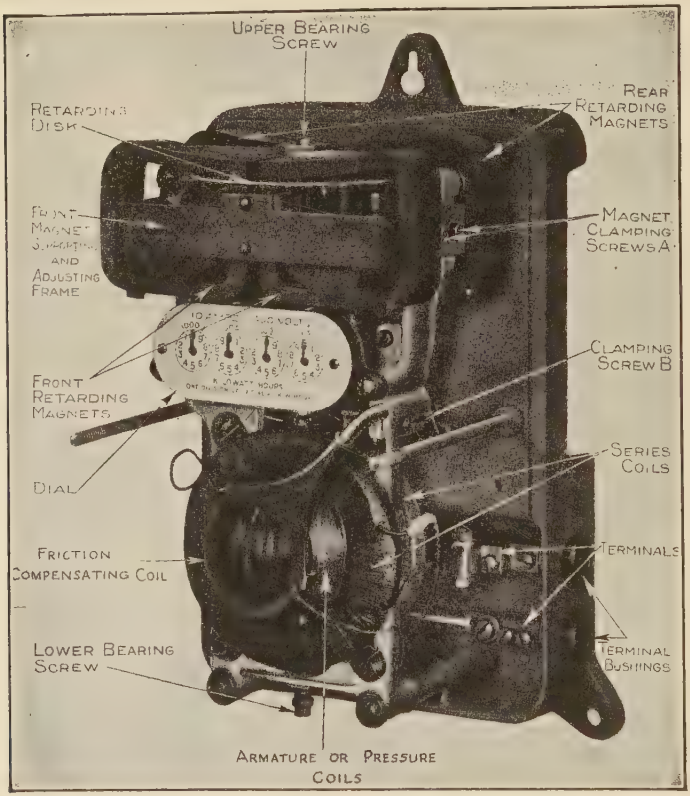


Fig. 95.—A d-c. watt-hour meter.

put. This is readily accomplished by inserting a reversing switch in the line.

80. Temperature and Specific Gravity Tests.—Each cell in a battery is seldom tested for temperature and specific gravity, but one cell of a group is selected on which these tests are made. This cell is known as the pilot cell and it is so situated that its condition is representative of the

condition of the other cells in the battery. Measurements of voltage, temperature, and specific gravity are made on the pilot cell and the values so obtained are considered as representative. Measurements should be made on each cell as well as on the pilot cell once a month after the equalizing charge.

A thermometer for measuring the temperature is shown in Fig. 10. This not only shows the temperature but the number of points that must be applied to the specific gravity to give the current value at the temperature indicated.

The hydrometer has been explained in a previous chapter. A reading of the specific gravity taken immediately after the addition of fresh water may be misleading unless the water and the acid have been thoroughly mixed. The diffusion of the acid is accelerated by the passage of an electric current through the cell; hence, specific gravity readings taken after a cell has been charged for some time are likely to be more accurate than those taken before charging. This is especially true if the charge has proceeded to the stage of gassing. Readings should not be taken while the cell is gassing as these will be invariably lower than the actual specific gravity. The temperature must also be noted and corrections to the observations made if accuracy is desired. In the case of very large cells the electrolyte is warmer at the top of the cell than at the bottom. The specific gravity is greater at the bottom of the cell due to this difference in temperature and to the tendency of the heavier liquid to settle. In some cases a small current of air may be forced through the solution in order to cause circulation and keep the density uniform.

The battery should be charged until the density of the electrolyte ceases to increase. The density of the electrolyte reaches a constant value when no more sulphate is available for conversion into active material and sulphuric acid. If originally the solution was of the proper strength, and if none has been spilled or lost through leakage, it will rarely be necessary to add more acid. The instructions of

the battery manufacturer should be followed in determining the proper value to which the specific gravity should be adjusted since the specific gravity between charge and discharge depends altogether upon the design of the cell, the relation between the space in the container for the solution, and the size and the number of the plates. Cells of certain designs have twice as much electrolyte as others of the same capacity, and, consequently, their specific gravity varies but half as much.

The densities of electrolyte for batteries used in tropical climates are adjusted for values as much as 70 points lower

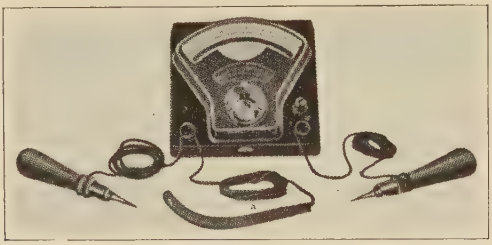


FIG. 96.—Voltmeter for cadmium testing.

than in the more temperate zones. Thus the maximum density of a starting battery in a tropical country is adjusted to 1,210, and the density of the solution for the same battery in a colder climate is adjusted to 1,280.

81. Voltage Tests.—For measuring the voltage of individual cells, the most suitable instrument is a low reading voltmeter, scale 0 to 3 volts. To facilitate reading, and to make good electrical contact, flexible leads, which terminate in sharp metal points set in a wooden handle, are attached to the voltmeter, Fig. 96. In making connections to the terminals of a lead-acid cell, the metal points are pushed or stabbed into the centers of the lead posts thus ensuring good electrical contact.

For making connection to the nickel-iron cell, a somewhat different device is used. This consists of a fork of fiber $\frac{3}{8}$ in. thick, to which flat metal contacts are attached. The handle and branches are each 1 in. wide by 4.5 in.

long. The distance between the centers of the branches at the ends is equal to that between the poles of the cell. The contact places are made of copper ⅞ in. wide and extend 2½ in. on either side of the branches to which they are fastened by rivets. The flexible voltmeter leads are soldered to the contact pieces. To insure good electrical contact when making measurements, the metal should be kept bright, clean, and wet with water.

The open-circuit voltage of a cell does not indicate its state of charge, but does indicate the absence or presence of internal troubles such as sulphation, short-circuited plates, etc. In all such cases the voltage will be below normal. The open-circuit voltage gives no indication of the incipiency of disorders, which is of fundamental importance in the maintenance of batteries, and hence it is of little practical value.

A very low voltage or reversed polarity is indicative of a short-circuit within the cell. This may be due to buckled plates, poor separators, or, more likely, to an accumulation of sediment in the bottom of the jar. If the short-circuit has been removed, a special connection may be made to the cell which is in trouble so as to give it an individual charge. Many large central station batteries have a permanent arrangement for giving any cell a special charge, independent of the rest of the battery.

Slight differences in voltage are remedied by giving the battery an equalizing charge, which is really an overcharge. This overcharging fully charges the low cells while the continued passage of the charging current through the fully charged cells simply causes them to gas. It is recommended that this equalizing charge be given every two weeks.

The voltage of a cell will vary with changes in density of the electrolyte, temperature, and age of cell. Because the internal resistance of the cell varies with the state of charge, the closed circuit voltage may be used as an indication of the charged condition of the cell.

Referring to the battery voltages given in Fig. 31, it is found that the voltage of a nickel-iron cell varies, at the

normal rate of discharge, from 1.50 volts per cell at the beginning to 0.90 volt per cell at the end of discharge. An approximate method of determining the state of charge of these batteries is to allow normal current to flow through the battery for a few minutes and then read the voltage. On a curve of voltage at normal rate of discharge mark a point which shows the same voltage as that read. The ratio between the interval of time from the beginning of discharge and the point marked, to the time total for discharge, represents the fractional part of the total charge that has been drawn from the battery. For example, if the voltage observed is 22.75 volts for a battery of 21 cells, and the distance in time from the beginning of the normal discharge curve to this point is 80 per cent of the total distance to point of complete discharge, then 80 per cent of the charge of the battery has been used and 20 per cent remains. Care must be used in making these measurements as a small error in voltage will make a large error in locating the point on the curve.

On account of the resistance of the intercell and intertray connectors, the sum of the voltages of the individual cells on discharge will be greater than the voltage read across the terminals of the battery. The difference represents the value of the drop in voltage in the connectors. This drop is proportional to the current flowing and increases as the value of the current increases. For this reason it is desirable to have the resistance of the connectors as low as possible in order to insure the maximum voltage under heavy discharge rates.

82. Test for Condition of Plates.—The positive plates of a lead storage cell that has been in active service for some time will have shed some of the active material; and when such a cell is charged, it will gas before the negative plates have received a full charge. The ampere-hour capacity of the cell depends upon the condition of both sets of plates, and hence it sometimes becomes necessary to determine the charged condition of each plate or group of plates separately. This is most conveniently

done by means of a third electrode whose potential is intermediate between the potentials of the positive and negative plates of the cell. This electrode must be of such material that its use will introduce no harmful substance into the electrolyte. Several different substances have been suggested and used for this purpose, but for the lead-

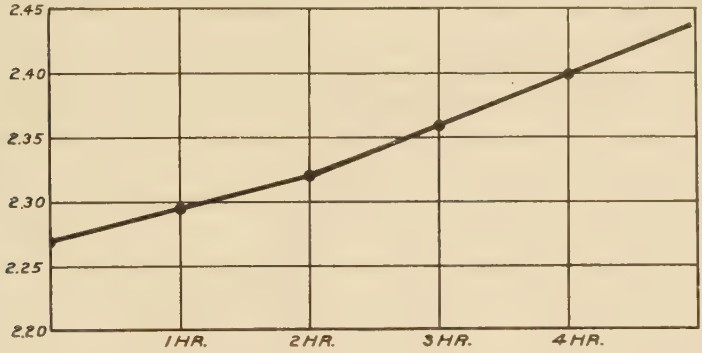


FIG. 97*a*.—Potential of positive plate above cadmium electrode on charge

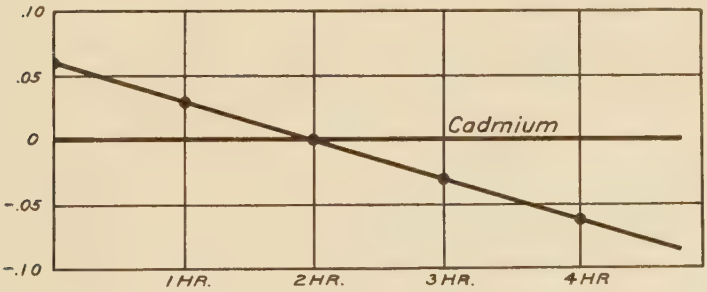


FIG. 97*b*.—Variation of potential of negative plate on charge.

acid cell an electrode of cadmium, and for the nickel-iron-alkaline cell one of cupric oxide are used. A lead-peroxide electrode is also sometimes used for the lead-acid cell.

The cadmium electrode is made from a stick of the metal about $\frac{3}{8}$ in. in diameter and about 6 in. long. To one end of this is soldered a piece of rubber covered copper wire for voltmeter connections. The cadmium pencil is then enclosed in a perforated rubber tube. The rubber tube is to prevent short-circuiting the cell plates when the

electrode is immersed in the electrolyte. The electrode thus prepared is immersed in sulphuric acid for several days, or until the surface of the cadmium is thoroughly corroded. The level of the acid must not reach the copper terminal.

When the condition of the cell is to be determined, the cadmium electrode is placed in the electrolyte, care being

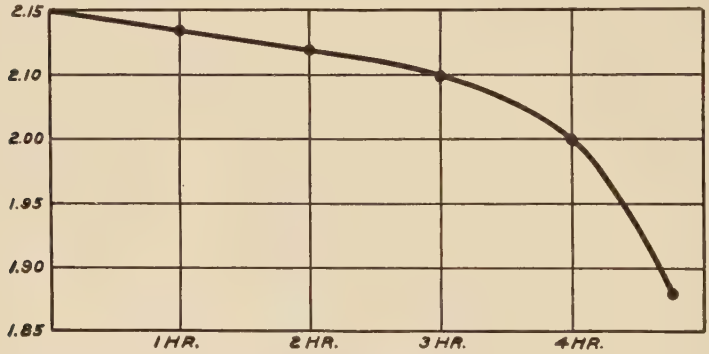


FIG. 98*a*.—Potential of positive plate above cadmium on discharge.

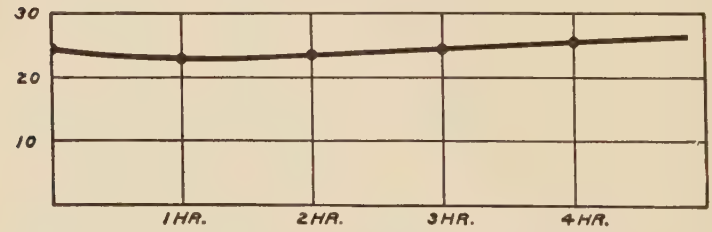


FIG. 98*b*.—Potential of negative plate above cadmium on discharge.

taken to see that the bare cadmium does not touch either plate, and the copper "lead" is connected to the negative terminal of a low reading d-c. voltmeter. To the positive terminal of the voltmeter is connected a flexible conductor which terminates in a sharp pointed spike, commonly called "sticker" or "stabber," Fig. 96. To make a reading the spike is pressed against the positive terminal of the cell and the voltmeter is read. Curve, Fig. 97*a*, shows the potential of the positive plate of the cell above that of the cadmium on charge. This relation is approximately a straight line. Curve, Fig. 97*b*, in a similar manner

shows the variation of the plate voltage of the negative plate to cadmium on charge. These curves show that the potential of the positive rises and that of the negative falls on charge. The algebraic difference between the two at any time gives the voltage of the cell.

Since on charge the voltage of the positive plates rises and that of the negative falls, it follows that on discharge these characteristics are reversed. This is disclosed by

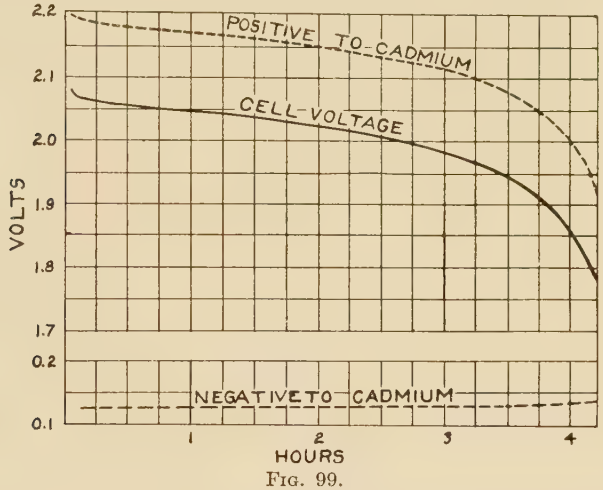


FIG. 99.

Fig. 98. The relative capacities of the positive and negative plates are indicated by the relative fall or rise of the potentials of the positive and negative on discharge. The case of low capacity positive plates with reference to the negative is shown in Fig. 99. The curves show that the potential of the negative has risen very slightly, while that of the positive has fallen to 1.9 volts. Likewise, Fig. 100 shows the discharge curves of a cell in which the negatives have low capacity as compared with the positive plates. This is disclosed by the curvature of the potential curve of the negative plates.

The shape of the plate to cadmium potential curve is an indication of the relative capacity of the two sets of plates.

The difference of potential between the negative plates and cadmium is so small that a slight error in the measure-

ment may produce a large percentage error in the result. The method of determining this difference of potential is thus important. There may be considerable error in obtaining the cadmium to negative plate potential by subtracting the cell voltage from the potential difference between cadmium and positive plate as measured by a voltmeter. This error may be avoided if the procedure be reversed and a low reading, high resistance voltmeter

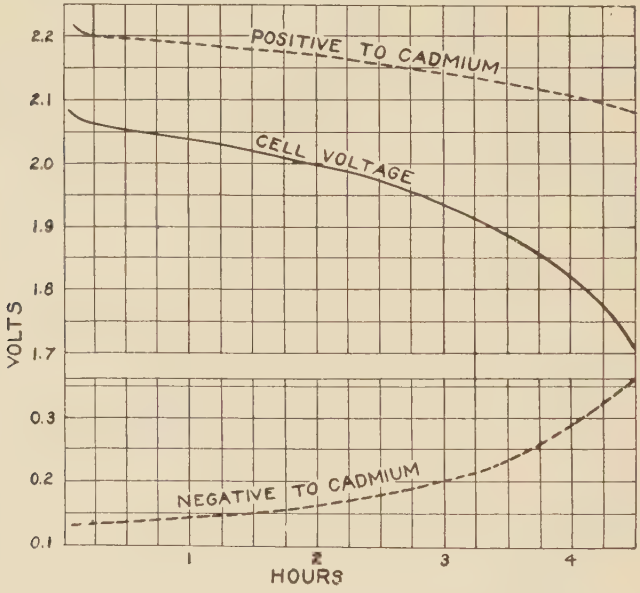


FIG. 100.

be used to measure the cadmium to negative potential. If to this is added the voltage of the cell, the result is the potential from the cadmium to the positive plate.

The Bureau of Standards in *Bulletin* 146 on "The Cadmium Electrode for Storage Battery Testing" gives the following conclusions in regard to the reliability of the cadmium test:

1. The cadmium electrode is accurate to about 0.02 volt provided the proper precautions are taken. It was found to be constant within 0.01 volt during several hours, but from day to day it varied as much as 0.02 volt.

Form of Record for Storage Battery Test—Log Sheet I

Battery of..... .... cells Type..... .....

Test made by..... Date.....

Time	Volts	Amperes	Density	Temperature	Remarks

Note.—The voltmeter, ammeter, hydrometer, and thermometer should be read as close together as possible and the time of the reading recorded.

Initial Charge or Test Discharge Report—Log Sheet II

Plant of.....at.....

consisting of.....cells, Type.....Plates per cell.....

Initial charge / Test discharge begun.....A. / P. M.....19.... Completed.....A. / P. M.....19....

Sheet No.....

Date	Time	Amperes	Ampere-hours	No. of cells in circuit	Total volts for cells in circuit	Average volts per cell in circuit	Pilot cell (No.)						Note.—Under "Pilot Cell" only "Pos. Cadmium" and "Volts" to be taken with the voltmeter; "Neg. Cadmium" to be calculated.
							Specific gravity	Volts	Cadmium		Temperature		
									Pos.	Neg.	Electro-lyte	Room	
													Remarks:
													Readings taken by
													.....
													Readings approved by
													..... {in charge / of work}

Instructions for Initial Charge.—Charge at the normal rate until the voltage and specific gravity show no rise for at least 10 hours, the readings being taken once an hour; th maximum voltage will probably be reached earlier than the maximum specific gravity, so that particular care must be taken that both voltage and specific gravity have reached the required maximum before the charge is stopped. This will require at least 60 **hours' charge at the normal rate,** or its equivalent at a lower rate, except for Types *B*, *C*, *D*, and the Two-Plate types, which require from 30 to 40 hours at the normal rate or its equivalent.

Test Report. Charge
Discharge—Log Sheet III

Plant of.....Company,

Battery (No.....) at.....Station. Date.....192....

Positive side											Negative side										
Time start					Time finish						Time start					Time finish					
Cell	Volts	Cadmium		Sp. gr.	Temp.	Cell	Volts	Cadmium		Sp. gr.	Temp.	Cell	Volts	Cadmium		Sp. gr.	Temp.	Cell	Volts	Cadmium		Sp. gr.	Temp.
		Pos.	Neg.					Pos.	Neg.					Pos.	Neg.					Pos.	Neg.		
1						20						1						20					
2						21						2						21					
3						22						3						22					
4						23						4						23					
5						24						5						24					
6						25						6						25					
7						26						7						26					
8						27						8						27					
9						28						9						28					
10						29						10						29					
11						30						11						30					

12						31						12						31				
13						32						13						32				
14						33						14						33				
15						34						15						34				
16						35						16						35				
17						36						17						36				
18						37						18						37				
19						38						19						38				

Temperature of room °F. Average height of electrolyte in.

Volts 50 cells Rate Amperes

Temperature of room °F. Average height of electrolyte in.

Volts 50 cells Rate Amperes

NOTE.—"Pos. Cadmium" and "Volts" only, to be taken with the voltmeter; "Neg. Cadmium" to be calculated.

Remarks:

Readings taken by

2. The cadmium electrode should be corroded several days in acid, a thorough state of corrosion being of greater importance than the exact size and shape of the electrode.

3. Amalgamation is not recommended since it makes the potential less negative and of uncertain value.

4. In case the surface of the electrode is allowed to dry, it should be soaked in acid for at least one-half hour before being used.

5. The depth of immersion should be made as great as possible, by adding electrolyte to the cell if necessary.

6. More steady readings are obtainable during discharge than during charge.

7. For accurate measurements of the potentials of storage-battery plates, the mercurous-sulphate electrode with a potentiometer is recommended.

8. The error in measurement with the cadmium electrode due to polarization is in many cases large, being proportional to the potential being measured. It is, therefore, many times greater in the case of the cadmium-positive than of the cadmium-negative potential.

9. The greatest error in the use of the cadmium electrode is due to polarization caused by a voltmeter of low resistance. Obviously this error may be avoided by using an instrument having a resistance of several thousand ohms. In case a voltmeter of low resistance must be used, the best procedure is to measure the cadmium-negative potential to which the cell voltage may be added to obtain the cadmium-positive potential. If a check upon the readings is required, then either a potentiometer or a high-resistance voltmeter is necessary.

Records for Battery Tests.—These vary widely and are determined to a great extent by the type of battery tested, purpose of the test, and use of the data recorded. Three forms of log sheets are shown. Log sheet I is very simple and is suitable for a small installation. Log sheets II and III are representative of those kept by a large storage battery manufacturing company.

RECAPITULATION

1. The more common tests for determining the condition of a storage battery are those for ampere-hour capacity, watt-hour capacity, temperature, specific gravity or density, voltage, and relative charge on the negative and positive groups of plates.

2. The ampere-hour capacity is obtained by discharging the battery at a constant rate for a definite or known interval of time and then multiplying the discharge rate in amperes by the time in hours. The ampere-hour capacity may most conveniently be obtained by means of an ampere-hour meter.

3. To determine the watt-hour capacity both the ampere-hours discharged and the average voltage during the period of discharge must be determined. The watt-hour capacity is the product of the ampere-hour capacity by the average voltage. For determining the watt-hour capacity of large storage batteries whose voltage is 100 volts or more, a direct-current watt-hour meter is well suited.

4. The average voltage of a battery is readily obtained by plotting a time-voltage curve, computing the area between the voltage curve and time axis, and then dividing this area by the length of the time interval. The area can be expressed in terms of the number of squares of the cross-section paper and the length of the time interval in terms of the horizontal dimension of each square. The ratio of area to length multiplied by the number of vertical divisions per volt will be the average voltage.

5. A pilot cell is that cell of a battery which is selected as representative of the group. Tests are made in the pilot cell, and the results of these tests are considered as applying to the other cells of the group.

6. The density of the electrolyte may vary with depth; hence, in making specific gravity measurements assurance must be had that the density of the electrolyte is uniform throughout. Density measurements should not be made immediately after the addition of water.

7. For measuring the voltage of individual cells a low reading, 0 to 3 volts scale, should be used.

8. If the positive and negative plates of a lead-acid cell have different ampere-hour capacities when one set is fully charged the other will not be. The charged condition of the two groups of plates of such a cell will be different, and to determine the relative charge the cadmium electrode is usually used. The algebraic difference between the voltages between cadmium and the positive plates and cadmium and the negative plates gives the voltage of the cell. A low reading, high resistance voltmeter is best suited for this test.

QUESTIONS

1. Name the common storage-battery tests.

2. What factors must be taken into consideration in comparing the ampere-hour capacity of two batteries?

3. Describe in detail how you would measure the ampere-hour capacity of a storage battery.

4. (*a*) What is the discharged voltage of the lead-acid cell?

(*b*) What is the discharged voltage of the nickel-iron cell?

5. The following data were obtained in testing the ampere-hour capacity of a 21-cell type A6 nickel-iron cell; calculate the ampere-hour capacity to a voltage of 0.90 volt per cell.

TABLE VIII.—DATA ON NICKEL-IRON CELLS

Time	Volts	Amperes	Temperature	Remarks
10:30	28.75	45	22.5	
10:37	26.5	45		
10:45	26.00	45		
11:00	25.75	45		
11:30	25.20	45	26.1	Room temperature 20 deg. Cent.
12:00	24.90	45		
12:30	24.50	45	29.7	
1:00	24.25	45		Potassium electrolyte, density 1,200
1:30	24.00	45	33.3	
2:00	23.75	45		
2:30	23.00	45	36.9	
3:00	21.90	45		
3:30	20.50	45	40.5	
4:00	18.25	45	42.3	

6. Plot the time-voltage and time-temperature curves for the battery of Question 5.

7. Calculate the average voltage for a discharge period of 5 hours for the battery of Question 5.

8. The battery of Question 5 was charged at 45 amp. for 8 hours. What is its ampere-hour efficiency when the discharge voltage is 0.90 volt per cell?

9. Calculate the watt-hour output for the battery of Question 5.

10. Assuming that the average charging voltage for the battery of Question 5 was 36.5 volts, calculate its watt-hour efficiency.

11. May a specific gravity measurement be made immediately after water is added to the cell? Explain why.

12. What is a pilot cell? When should tests be made on other than the pilot cell?

13. If one cell in a battery has a lower voltage than the pilot cell, what conditions may cause the low voltage?

14. When is a cadmium test necessary?

15. Describe the process of making a cadmium electrode test.

16. (*a*) What is the difference of potential between the positive plates and the cadmium electrode when the positive plates are fully charged?

(*b*) What is the difference of potential between the cadmium and the negative plates when the plates are fully charged?

17. What precautions should be taken to get reliable results in making the cadmium test?

18. Will the results be reliable if a low resistance voltmeter is used in measuring the cadmium to plate voltage? Why?

19. What causes the maximum error in cadmium to plate voltage measurements?

20. Why is a high resistance voltmeter or potentiometer preferable to a low resistance voltmeter in making cadmium tests?

CHAPTER IX

MAINTENANCE OF STORAGE BATTERIES

83. General.—Some of the topics discussed in the chapters on charging and testing might properly be included in this chapter. There are, however, certain mechanical operations associated with the care and operation of batteries which are not properly classified under the headings of preceding chapters. This miscellaneous group of operations is briefly treated in this chapter.

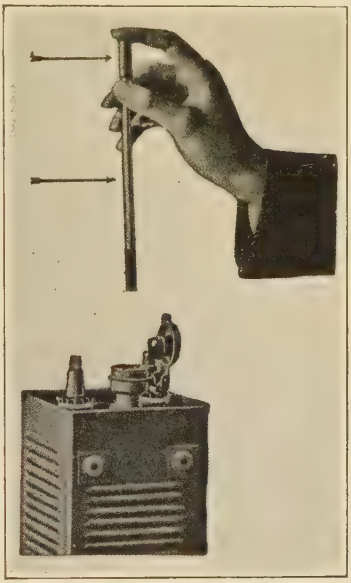


FIG. 101.—Measuring the height of the electrolyte.

84. Replenishing the Electrolyte.—The water of the electrolyte in both the lead-acid cell and the nickel-iron-alkaline cell evaporates, and on charge, it is decomposed. In the maintenance of storage batteries, the individual cells must be inspected to see if the electrolyte has fallen below the proper level and, if so, to restore it by the addition of distilled water. The inspection is simple for cells with glass jars or jars with open tops, but for sealed cells, such as automobile batteries and the Edison cell, the height of the electrolyte above the plates is most easily determined by the aid of a glass tube as shown in Fig. 101. The tube must be not less than $\frac{1}{4}$ in. in diameter or else the capillary attraction will raise the electrolyte higher than it actually is. To determine the height of the electrolyte above the plates, insert the tube until the tops of the plates are touched,

close the upper end with the finger, and withdraw the tube. The height of the liquid in the tube indicates the height of the liquid above the plates in the cell. The height of the electrolyte should be tested before and after charging, but not during charge, for the gassing then taking place raises the liquid above the normal level.

To facilitate the replenishing of the electrolyte the Edison Storage Battery Company has placed on the market two forms of fillers, one for *A*, *B*, *G*, and *T* type of cells, Fig. 102, and one for *F*, *M*, and *W* type of cells, Fig. 103. The filler shown in Fig. 102 automatically indicates, by the ringing of the bell, when the cell is filled to the proper level.

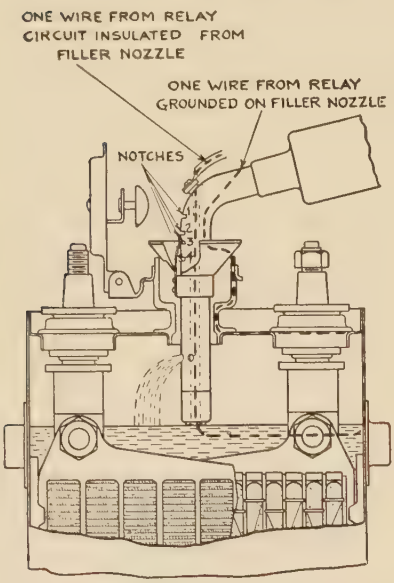


FIG. 102.—Principle of filler for nickel-iron cells.

The operation of the filler will be readily understood from Fig. 102. One wire of the bell circuit is metallically connected to the nozzle which in turn makes metallic contact with the vent tube of the cell. The other wire of the bell circuit is insulated from the nozzle but terminates in a metal collar on the nozzle end. The proper distance which the nozzle is to be inserted into each type of cell is indicated by notches. When the electrolyte reaches the proper level, it closes the bell circuit and the bell rings. By the use of this device the cells can be filled quickly and without the spilling or slopping of the water.

The filler should always be tested before use to see that it will indicate properly. It should not be used when filling with electrolyte as the electrolyte is a conductor and its presence in the tube will result in ringing the bell.

For replenishing the water in the *L*, *M*, and *W* type of Edison cell the filler shown in Fig. 103 is convenient. These filler cups have different lengths of stem for different types of cells and they operate as follows: When the stem of the filler cup is inserted into the filler opening of the cell, the rubber gasket on the stem seals the cell; and by pressing down on the spring at the top, the valve at the bottom of the cup is opened, permitting the water to flow into the cell. The air in the cell escapes through the vent pipe which dips under the water in the cup. When the solution

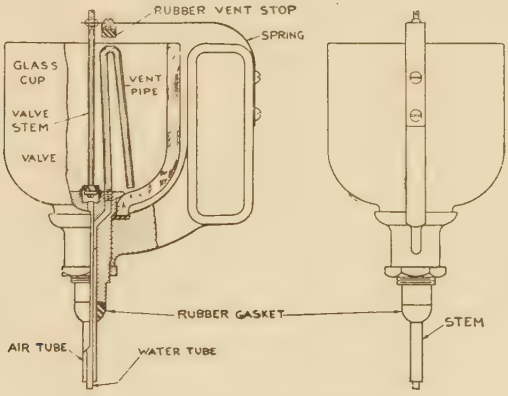


FIG. 103.—Filler for nickel-iron cells.

reaches the bottom of the stem, the vent pipe is sealed and the flow of water ceases.

85. Cleaning.—One essential of efficiency is cleanliness. Storage batteries like all other apparatus will give better and longer service if kept clean. Furthermore, cleanliness is an indication that the apparatus is well cared for. The accumulation of dust and other foreign matter, combined with the electrolyte vapor, forms conducting paths from one electrode to the other for leakage current which will not only discharge the cell but cause corrosion of the terminals and other parts of the cell. To prevent this slow, but, nevertheless, continuous deterioration, the cells must be cleaned regularly and corrosion prevented by protective coatings. For lead cells, the terminals are often coated

with asphaltum paint, but a coat of vaseline is even more effective, and its use is becoming extended. Every charge and discharge of a lead cell tends to loosen some of the lead peroxide on the positive plates. This action is accelerated if either the charging rate or the temperature or both are high. This liberated oxide collects on the bottom of the jars; and if it is not removed, an amount sufficient to short-circuit the plates may accumulate. The length of time a cell will operate before it needs cleaning depends upon the service conditions, frequency and rate of charge and discharge, and temperature and strength of the electrolyte.

Where it is impossible to ascertain the amount of sediment by mere inspection, as in the glass enclosed cells, the rate at which it is accumulating can be ascertained approximately by removing the element after about 75 discharges, siphoning the acid out of the jars without disturbing the sediment, and measuring the depth of the accumulation. After another 25 or so discharges another cell of the battery may be examined in the same way. The relative depths of sediment in the two cases is a measure of the rate of its accumulation, and from this rate the length of time the battery may be safely operated before cleaning can be estimated. A decrease in the specific gravity of the electrolyte throughout the battery, when not due to insufficient charging, is an indication of the accumulation of sediment. After each inspection the jar should be washed out, the elements replaced, and the electrolyte carefully poured back. The electrolyte can readily be transferred from one container to another by a siphon, Fig. 104.

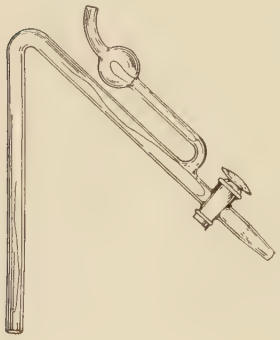


Fig. 104.

When the accumulation of sediment necessitates its removal, the cleaning process will be modified by the kind of jars used, but in general the following procedure will

apply: Fully charge the battery before disconnecting the cells. Remove the elements from the jars and stand them on edge in a row on a clean board or bench. Spread the plates carefully, remove the separators, and then gently play a stream of water over them to wash off any loose sediment. Immediately after washing, the elements should be placed in pure water to prevent the absorption of oxygen by the negative plates.

When the plates have been cared for, the electrolyte may be siphoned out and the jars thoroughly cleaned. Immediately upon reassembling the plates in the jars, new electrolyte of the proper density should be added. If the plates were kept wet, no heating will take place when the electrolyte is added; but if they were permitted to dry, some heat is likely to develop and the battery must be permitted to cool before charging. The manufacturers furnish instruction books for the care and maintenance of each type of cell, and these should be followed.

86. Cleaning Nickel-iron Cell.—The following is an extract from the instruction booklet on the "Care and Operation of the Edison Alkaline Storage Battery:"

"The cells, trays, and battery compartment must be kept dry, and care must be taken that dirt and other foreign substances do not collect at the bottom or between the cells.

"A special battery oil is prepared by the manufacturers for the purpose of preventing accumulation of dry electrolyte crystals, thus making it possible to clean the battery readily. No other oil should be used as it may cause trouble.

"The tops of the cells should be given a light coat of this oil. It should be applied to the cover of the cell, and to the outside of the filling aperture; it can also be applied to the inside of the filling aperture with beneficial results. A small brush is most convenient for applying the oil. Care should be taken that none of the oil gets inside of the lugs or connectors, or on the poles of the cells. All connections should always be kept clean and dry. A special vaseline compound is also furnished which can be used in the same

manner, except that it must not be used inside the filler opening or allowed to get into the interior of the cell.

"Thorough cleaning cannot be done without removing the battery from the compartment. Under ordinary conditions, such cleaning will be necessary about once in two months. A steam or air blast will be found most satisfactory for the purpose, but this must not be used on cells while they are in the compartments. It has been found that a pressure of 70 lb. with a 1-in. rubber steam hose about 10 ft. long into which has been inserted a piece of iron pipe about 12 in. long with an orifice $\frac{1}{8}$ in. in diameter will give wet steam with a velocity sufficient to clean the battery satisfactorily. This orifice can be made by plugging one end of an iron pipe and drilling out with a $\frac{1}{8}$ in. drill. When removing incrustations from the tops of cells, do not allow them to fall between the cells. Make sure that cells, trays, and compartments are dry before replacing the battery."

Dirt and dampness are likely to cause current leakage which may result in serious injury to the cells.

87. Receiving a New Battery.—Small cells, especially those for vehicles, are usually shipped assembled and packed in gable or pyramidal roofed cases to keep them upright during shipment. Large cells, and even small ones with glass jars, are shipped disassembled. These must be assembled before installation.

The process of unpacking and placing in service of sealed or vehicle batteries is comparatively simple; nevertheless, certain precautions should be taken to see that no damage is done. The top of the packing case should be removed by means of a box opener, if available, care being taken to keep the battery upright to avoid spilling the electrolyte.

All the packing material, which is usually excelsior, should be removed from the top and sides of the battery. The discolored condition of the packing will indicate whether any of the cells leaked or the case has been tipped in transit. When the battery is removed from the case, it should be carefully inspected to see that it is in good condition.

"All of the vent plugs should be removed or opened and the height of the electrolyte noted. This should be approximately ½ in. above the top of the plates. If the electrolyte is uniformly below the proper level, it indicates that evaporation alone has taken place and sufficient distilled or pure water must be added to bring the level to the proper height. If the level of the electrolyte is at its proper height in some cells and below in others, it indicates that electrolyte has been lost, due either to spilling or leakage from a broken jar. The cells low in acid should be filled to the proper height with sulphuric acid electrolyte of proper specific gravity. If the loss is due to the tray having been over-turned during the shipment, the excelsior and packing around the top will be wet and electrolyte probably will have been spilled from all cells. If the loss is due to a broken jar, the excelsior at the bottom of the tray and the bottom itself will be wet, while the excelsior at the top may be dry. The broken jar must be replaced and sufficient electrolyte added to make up for the loss.

"Low cells in the nickel-iron type battery should be filled to one-half inch above the tops of the plates, or to such height as is indicated by the instruction book for this type of cell, with distilled water, unless electrolyte has been spilled, in which case the alkaline electrolyte should be added as obtained from the Edison Storage Battery Co.

"When all points mentioned have been attended to and the battery appears to be ready for use, lead batteries should be given an equalizing charge. If, after this charge, the specific gravity of the electrolyte is not at its proper point, it is an indication that the same quantity of acid spilled or otherwise lost in transit has not been replaced. The specific gravity should then be adjusted. After this, the battery should be put on charge at the low rate stated on the name plate. The charge should be continued at this rate until all cells are gassing uniformly. The current then should be reduced to about one-half this value and the charge continued for about 3 hours, when the battery will be ready for service. Such a charge is called a "freshening"

or "conditioning charge." Before putting the battery into service, however, the specific gravity of each cell should be recorded, with the date. Such readings serve to indicate the condition of the cells and to show approximately to what point the gravity should come at the end of future charges.

"When preparing alkaline batteries for service, after the electrolyte has been brought to the proper height, the batteries should be charged at the normal rate for rather more than the usual time."[1]

In unpacking the disassembled cells, all material should be handled carefully. The contents of the packing cases should be closely examined for breakage as cracked jars must not be used.

88. Battery Room.—The proper location of a stationary battery is important. The room should be plain, well ventilated, and dry. Although plenty of light is desirable, the battery should not be exposed to direct sunlight. The walls of the room should be of brick or some similar material which is not readily attacked by the acid fumes, and all exposed metal work should be thoroughly painted with asphaltum paint or preferably vaseline.

The floor of the battery room should have a slope of about 1 per cent in order to permit of its thorough washing. The most satisfactory floor depends upon the type and size of installation. For large battery rooms, preference is now given to what is known as a mastic floor which consists of an asphaltum compound, with an acid-resisting aggregate. A fan should be installed so as to draw air into the room near the floor at the end where the cell switches are located and exhaust it at the other end near the ceiling. There is more likely to be a deposit of spray in the room with a pressure system than with an exhaust system of ventilation. The fan is protected from the corrosive action of the spray by introducing perforated lead screens or glass baffle plates between it and the battery room and by making its blades of bronze.

[1] *Circular* 92, U. S. Bureau of Standards.

89. Installation of Battery.—To economize space and to make each cell accessible, the batteries are usually mounted on benches or racks as indicated in Figs. 105 and 106. The

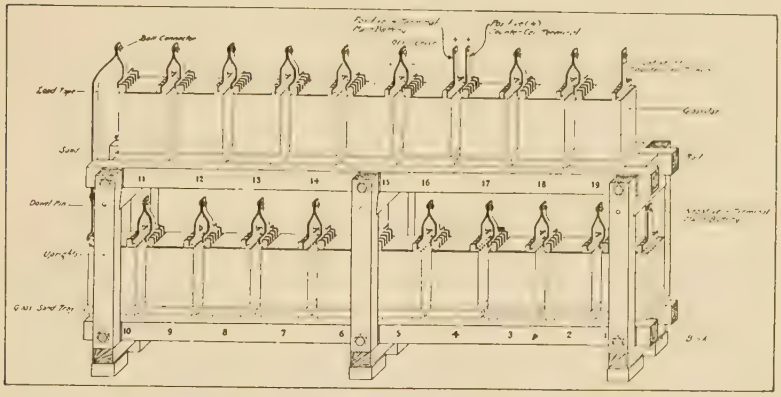


FIG. 105.—Bench mounting of cells.

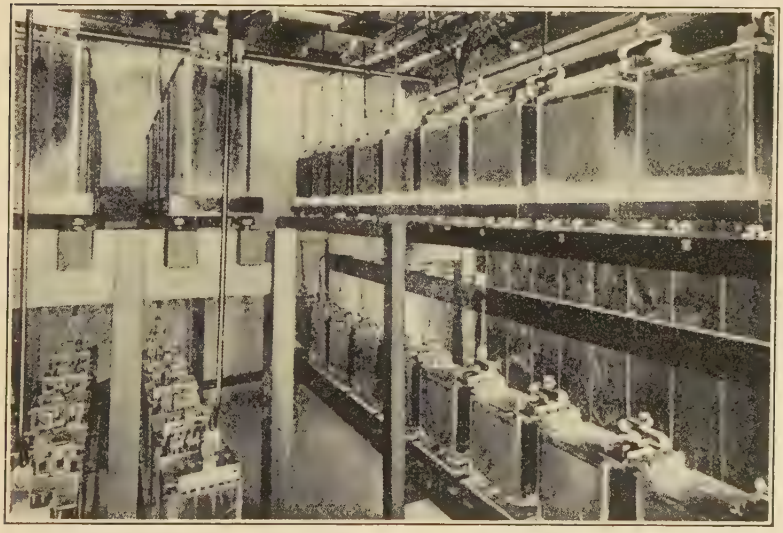


FIG. 106.—Battery installation.

individual cells are placed in sand trays, to equalize the pressure over the bottom of the jar, Fig. 107, or glass insulators, Fig. 108. The containers of the largest types of central station cells are usually lead-lined tanks, Fig. 109.

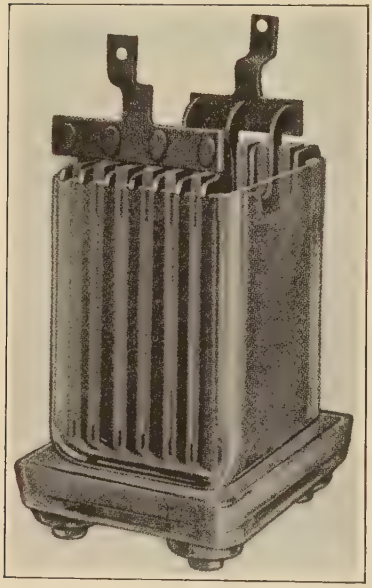


FIG. 107.

FIG. 108.—Glass insulator.

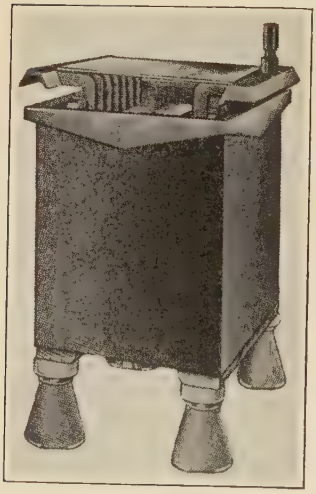


FIG. 109.—Lead-lined tank.

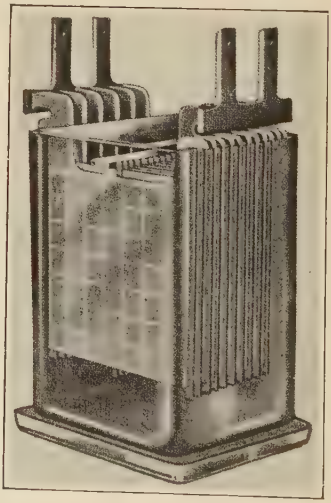


FIG. 110.—Glass jar with spray plate.

These are mounted on glass insulators as shown. Oil insulators are commonly used in the larger installations, in order to eliminate the slightest possibility of leakage current which might eat a hole by electrolytic action in the lead lining. Glass plates are commonly installed over the larger cells in order to catch the spray from the cell when it is gassing, Fig. 110. The floor, tank, and insulators under a battery of such cells must be very carefully designed in order to support the weight. A 10,500

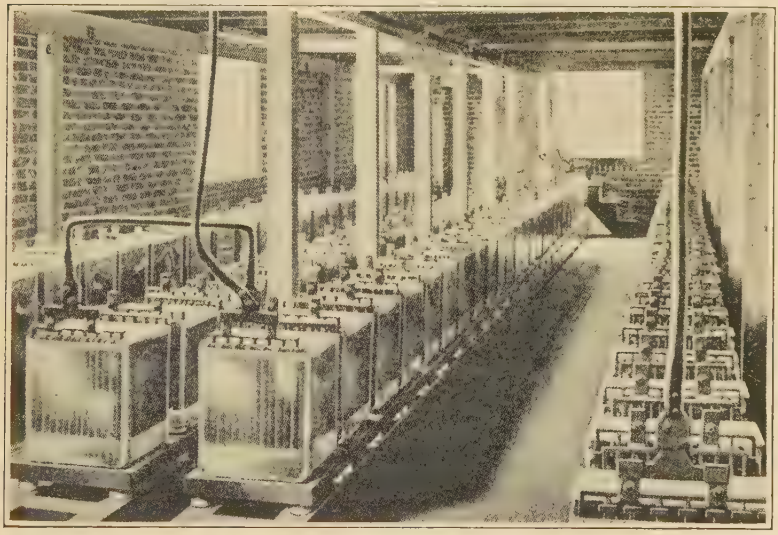


Fig. 111.—Large battery installation.

ampere-hour cell with a lead-lined tank 7 ft. $\frac{3}{4}$ in. long, by 21$\frac{3}{4}$ in. wide, and 3 ft. 7$\frac{11}{16}$ in. in height weighs 6,800 lb.

The cells should be so located in the room that they will be easily accessible, and if practicable should be in one tier, Fig. 111. Where two or more tiers are necessary, the clearance over the jars should be at least equal to the height of the jars, Fig. 106. If sand trays are not provided, the jars may rest directly on a board or plank, the plank being insulated from the rack or shelf by glass insulators.

90. Assembly of Cells.—When the jars or tanks are in place and properly spaced, the elements are assembled.

and placed in the tanks as shown in Figs. 112 and 113. The elements for the glass jar type of cell are usually assembled at the factory and are shipped ready for installation. The plates of each cell are "burned" to common crossbars, the negative to one and the positive to the other. The elements of one cell are joined to the elements of the neighboring cells by bolting the lead terminal straps together by means of lead-covered brass bolts.

Elements for the lead-lined tanks, that is, for large cells, must be assembled at the place of installation. The plates are shipped disconnected and must be grouped by joining the negative and positive plates to busbars which connect

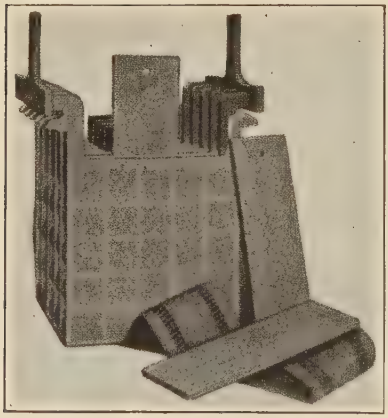


FIG. 112.—Assembly of battery elements.

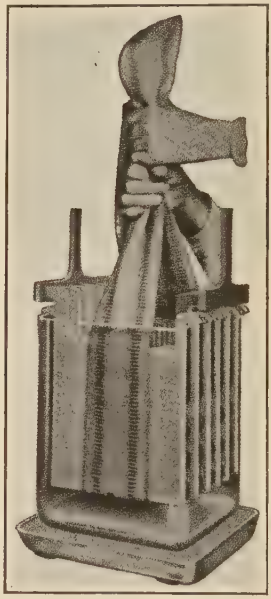


FIG. 113.—Placing elements in a jar.

adjacent cells. The plates are joined to these common busbars by "burning."

The electrolyte may be purchased of the manufacturer, or pure sulphuric acid may be diluted with distilled water to the proper density at the place of installation. Earthenware jars, large glass jars, or lead-lined tanks must be used for the preparation of the electrolyte. As already pointed out, the acid should be poured slowly into the water, and the mixture should be stirred continuously, for if this

is not done enough heat may be developed to generate steam and thus cause an explosion. Table I, Chapter I, shows the relative amount of water and acid necessary to produce electrolyte of any given density.

The fact that when given volumes of water and sulphuric acid are mixed the resulting volume is less than the sum of the two volumes makes it troublesome to calculate the resulting density from a mixture of known volumes

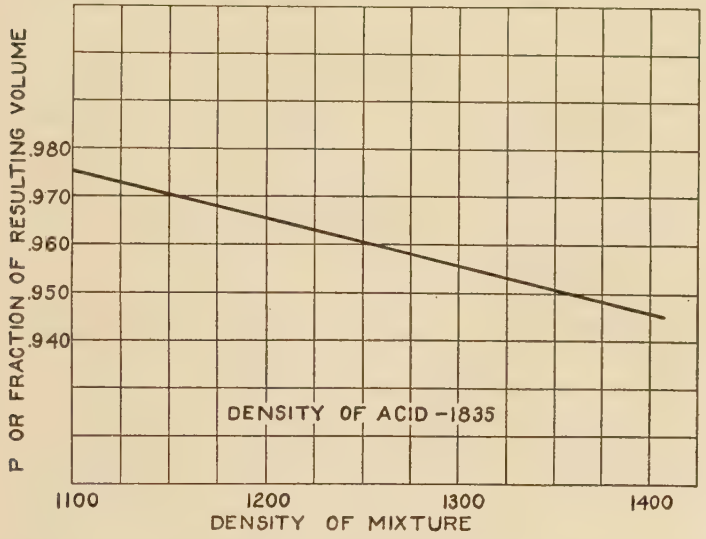


FIG. 114.—Relative volume of electrolyte and component liquids.

unless the per cent shrinkage is known. This varies with the concentration as shown by curve, Fig. 114. If this is assumed to be a straight line, between the densities taken, then by the aid of this curve and the following formula, the amount of water needed to form a solution of a required density can be approximately calculated.

Let W = volume of water used
S = volume of sulphuric acid
p = fraction the combined volume is of the sum of $W + S$
d_s = density of sulphuric acid
d = density or specific gravity of mixture
1,000 = density of water.

Then $1{,}000\ W + d_s S$ = combined weight of mixture
$(W+S)p$ = resulting volume.

Hence

$$d = \frac{1{,}000\ W + d_s S}{(W+S)p}$$

and

$$W = \frac{(d_s - dp)S}{dp - 1{,}000}.$$

If we wish to calculate the number of parts of water by volume which must be combined with one part of acid, then $S = 1$ and we have

$$W = \frac{d_s - dp}{dp - 1{,}000}.$$

The value of p for any required density is taken from curve, Fig. 114.

EXAMPLE

How much water by volume is necessary to mix with one part of acid, density 1,835, to form a solution whose density is 1,250 at a temperature of 70 deg. Fahr.?

SOLUTION

$d_s = 1{,}835$
$d = 1{,}250$
$p = 0.960$ from curve.

Then

$$W = \frac{1{,}835 - 1{,}250 \times 0.960}{1{,}250 \times 0.960 - 1{,}000} = 3.17$$

which is approximately the same as that given in Table I, Chapter I.

If the density of the sulphuric acid is other than 1,835, the formula will no longer give correct results since the per cent shrinkage is different.

When the prepared electrolyte has cooled to the temperature of the room, it may be siphoned into the assembled cells. If siphoning is inconvenient, the electrolyte may be poured into the jars from a porcelain or earthenware pitcher. Great care must be taken so as not to splash the electrolyte as it will corrode or burn nearly everything with which it may come into contact.

91. Dismantling Lead-acid Cells.—The dismantling of stationary unsealed cells is not an intricate process, although sometimes it may be difficult on account of the weight of the elements. On account of the permanent connection and sealed condition of vehicle batteries, under which term are included automobile lighting and starting batteries, their dismantling is somewhat more intricate. The following discussion is limited to these batteries.

(*a*) *Preparation of Battery for Dismantling.*—To make certain that no foreign matter will get into any of the cells, first clean thoroughly the top of the battery with a brush and cloth dampened with ammonia. If the battery consists of many cells, before starting to dismantle it make a sketch showing the relative location of cells, intercell connections, and terminals for guidance in reassembling.

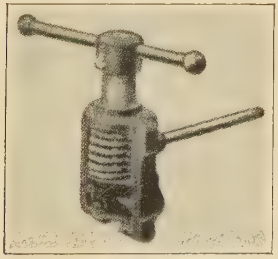


FIG. 115.—A cell terminal puller.

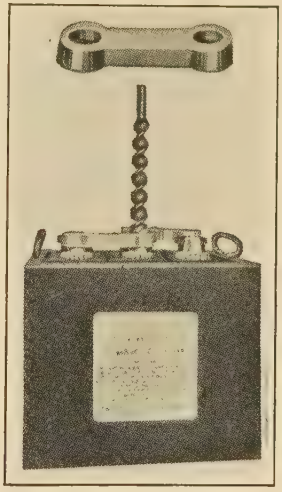


FIG. 116.

(*b*) *Removal of Connectors.*—The exact method of removing the terminal connector will vary somewhat with the type of connector used, and the tools available. A rapid method is to use a puller of much the same form, although smaller, as is used for removing pinions and gears from shafts, Fig. 115. The puller is slipped over the connector with the plunger over the center of the post. The plunger is then gradually turned down until the connector is pulled free from the post. The use of the puller eliminates boring out of the connectors but is liable to leave the post rough.

This roughness must be trimmed off on reconnecting the cell.

Another method of removing the connector is first to center punch the tops of the terminals and connectors over the terminal posts and then bore out the connector with a twist drill or bit approximately of the same diameter

Fig. 117.

Fig. 118.

as the post, $\frac{5}{8}$ in. for $\frac{3}{4}$-in. posts and $\frac{7}{8}$ in. for 1-in. posts. The hole should not be bored any deeper than is absolutely necessary or else the post will have to be built up on reconnecting, Fig. 116. When the connectors have been bored out to the proper depth, they may be pried loose from the

Fig. 119.

Fig. 120.

posts by means of a strong screwdriver as indicated in Fig. 117. To avoid damage to the box or to the jar a strip of wood should be laid across the top of the box or cell for a fulcrum, then by prying first on one side of the post and then on the other the connector is loosened. In case difficulty is experienced in freeing the connector from the post, heat may be applied until the lead is softened.

(*c*) *Removal of Element.*—Before using any flame around the battery, the vent plugs should first be removed, and all hydrogen gas expelled from the cells with a hand bellows or compressed air. Mixtures of hydrogen and oxygen are explosive, and unless the hydrogen is first driven off, the application of the flame may cause an explosion.

To soften the sealing compound around the edges of the covers, play a gas or torch flame over the compound, Fig. 118, using care not to burn or scorch the covers. Move the flame back and forth until the compound has softened sufficiently to be readily removed with a hot, plumber's lead scraper or putty knife. When the compound has been removed from the edges of the top covers, apply heat again to soften the underlying compound, and with a screwdriver inserted under the edge gently pry the covers off, Fig. 119. The covers should come off easily; if they do not, apply heat over their surface so that a slight force will lift them.

After the top covers have been removed, the underlying compound is heated as before, and as soon as the compound has softened, it should be removed with a hot screwdriver or putty knife. If too much heat is applied, the compound is likely to run and its removal become difficult. More satisfactory results will be secured if a small flame is slowly played over the surface for several minutes than if the process be hurried by using a strong flame. When the compound has all been scraped off the top of the inside cover, the gas flame is run around the junction between the cover and the jar for an instant and then a hot putty knife is run around the edges between the cover and jar. This will loosen the cover from the jar and permit the easy removal of the element. This operation should be performed rapidly, as the compound cools and sets quickly.

Place the jar and element or battery, if it is a small one, on the floor and hold it firmly between the feet; grasp each post with a pair of pliers and lift the element and inside cover out together, Fig. 120. As soon as the ele-

ments are lifted above the jar, tip and place them at an angle on top of the jar to drain for 5 min., Fig. 121. While the elements are draining, heat the compound around the posts and remove the covers. Clean the covers thoroughly and wipe off the edges with a cloth dampened with dilute ammonia. If the covers have been warped by the heat, they may be straightened by first placing them in boiling water until they are heated through, and then laying them flat on a smooth surface to cool.

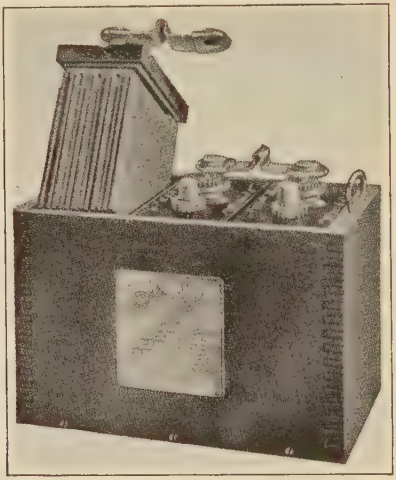


Fig. 121.

The elements should not remain exposed to the air for more than 15 min. on account of the rapid oxidation of the negative plates and consequent heating. To prevent this they should be kept wet by sprinkling water on them or, preferably, by placing them in a jar of water until they can be taken care of.

(*d*) *Removal of Separators.*—The relative ease or difficulty that will be experienced in removing the separators will depend upon their condition as well as upon the size and thickness of the plates of the elements. If the plates are thick and large, more difficulty will be experienced in separating them than if they are thin; and again if the

separators have deteriorated to such an extent that they are brittle, the plates will have to be spread sufficiently to permit the removal of them in pieces. The manner of separating the positive from the negative plates is shown

FIG. 122.

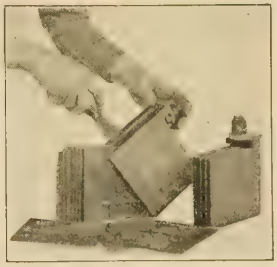


FIG. 123.

in Fig. 122. The separate elements are grasped firmly and worked back and forth until they are loosened and can be pulled apart. A putty knife is then slid in between the negative plate and separator, Fig. 123. This loosens the separator and permits its easy removal.

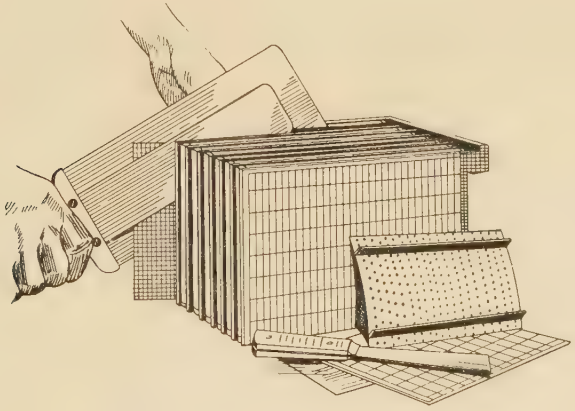


FIG. 124.

If it is necessary to use the separators again, then the use of a "separator inserter," Fig. 124, will facilitate the work. The broad side is used next to the negative plate to loosen the separator so that it can be removed without breaking.

As a rule it is not advisable to use wood separators over again, although rubber separators may be used indefinitely.

(*e*) *Removal of Jars from Box.*—On account of the limited space available, and the necessity for rigid construction, the cells of automobile lighting and starting batteries are compacted firmly in a box. After the elements have been removed, any defective jar must likewise be removed. To loosen the sealing compound fill the jar with hot water and allow it to stand for 5 min. When the compound has softened, take hold of the edges of the jar to be removed with two pairs of pliers and with the box held firmly between the feet pull straight up. Care must be exercised so as not to damage adjacent jars.

92. Assembly of Vehicle Batteries.—New vehicle batteries are usually assembled at the factory and are shipped ready for installation. Cells that have been dismantled for repair or storage must be assembled before being placed in service. The following directions for the assembling of vehicle batteries is abstracted from the Bureau of Standards *Circular* 92 and pamphlet on Care and Repair of Automobile Batteries published by the Gould Storage Battery Co.

(*a*) *Insertion of Separators.*—To insert new separators, place the elements on edge and insert the new separators from the bottom, being careful to have them project equally on both sides of the element, Fig. 125. If grooved wood separators only are used, the grooved sides of the separator should be next to the positive plate. When rubber sheets are also used, they should be inserted with the wood separator and between the grooved side of the separator and positive plates.

(*b*) *Placing Element in Jar.*—To place the automobile battery element in a jar, grasp it firmly by the terminal posts and lower it carefully into the jar. This should be done very carefully to avoid breaking the jar. To install the heavier element of the vehicle battery, place the element on edge, projecting slightly over the edge of the bench, and place the jar over the plates, as in position for

draining the element. Then lift the jar and element in this position to the floor and push the element into place. It is preferable to delay putting the electrolyte into the cell until the element is in place and the cell is ready to

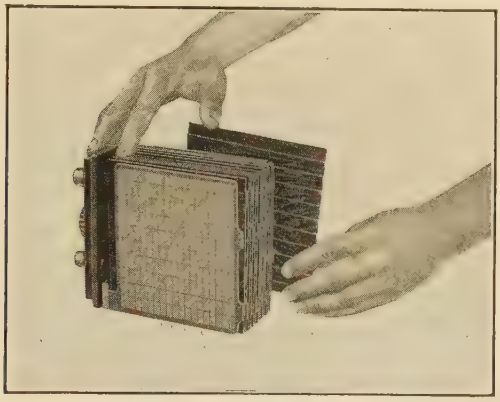


FIG. 125.

be sealed. In fact the electrolyte may be poured in through the vent after the cell is sealed.

(*c*) *Sealing the Jars.*—Before placing the covers they should be thoroughly cleaned of all sealing compound. The inside of the jar near the top should likewise be cleaned and wiped with a cloth dampened with dilute ammonia. This may well be done before inserting the element. Both jar and cover must be free of all acid or else the compound will not adhere firmly to the surfaces. In using ammonia care should be taken that none of it gets into the electrolyte.

FIG. 126.

Before putting on the cover, place the soft rubber gaskets, if used, over the posts. If rubber gaskets are not available and the lower cover does not fit snugly around the post, the opening may be calked with hemp twine or tow to prevent the hot compound from flowing into the jar. In case the cover cannot be made to fit while the jar is cold, the jar may

be warmed on the outside with a flame until it becomes flexible enough to allow the cover to fit properly.

The sealing compound is conveniently heated in a coffee pot on a gas stove, Fig. 126. From this it can likewise most conveniently be poured over the top of the cells. Sufficient compound should be poured over the top to fill all spaces and reach to a height level with the top of the case, and to a uniform depth. Where a top cover is used,

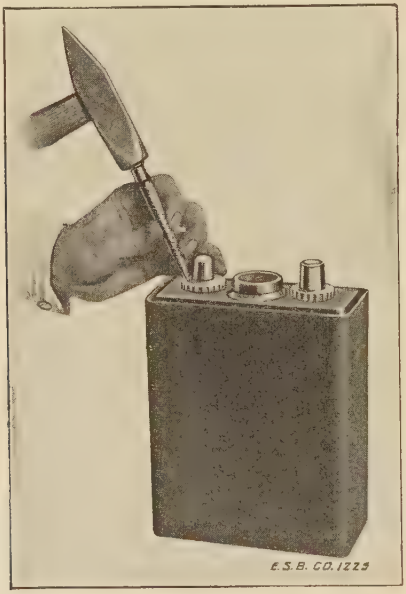


Fig. 127.

the top of the compound and the cover should be slightly heated before the cover is put in place.

If electrolyte is poured into the cell before it is sealed, the posts and edge of jar must first be wiped with dilute ammonia to neutralize the acid, and then left to dry before sealing. Where a sealing nut is used around the post, this is locked in place as shown in Fig. 127.

93. Lead Burning.—The term "lead burning" is in reality a misnomer, since no burning is really meant. By lead burning is meant the process of joining two pieces of

lead by fusion, that is, melting the two pieces together. This is done by pouring superheated lead around the joint, or, more commonly, by fusing together the adjoining surfaces by a blow-pipe flame or the heat of an electric current. The flame for lead burning is usually formed by the burning of some combustible gas under pressure with oxygen. The most widely used gases are illuminating gas, hydrogen, and acetylene. The oxygen may be in the pure state, unmixed with other gases, or in the form of compressed air. Hydro-

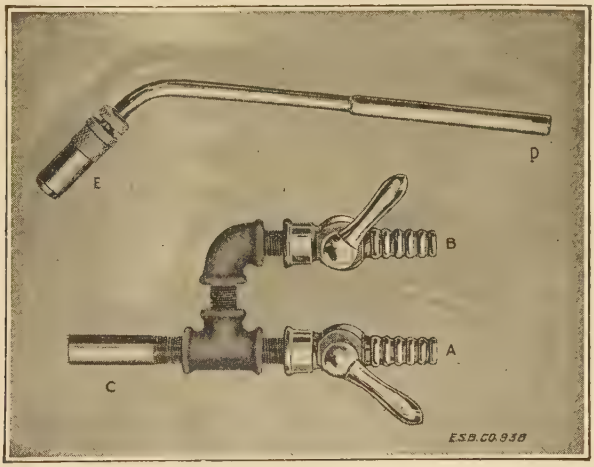


Fig. 128.

gen and acetylene are not so economical as illuminating gas, and they produce a flame whose temperature is too high for lead burning. Perhaps the most satisfactory and economical combination of gases is oxygen and illuminating gas. Only one tank is necessary, as the illuminating gas can be taken directly from the city mains.

The two gases are mixed in a blow-pipe or torch, Fig. 128. The oxygen tank is equipped with a reducing pressure valve, and each gas is led through a separate rubber tube to the blow torch. The function of the torch is to mix the oxygen properly with the illuminating gas. The quantity of each gas admitted must be regulated to obtain complete combustion, thus producing a neutral flame. When oxygen

is used in conjunction with gas from the mains, it is a good plan to install a protective device between the blow-pipe and the gas main. This protective device is to prevent the flow of oxygen into the gas mains where it may cause a serious explosion. Figure 129 shows the design of a safety device which will be found effective. The pipe from the gas main is run vertically down the wall about 3 ft.; to this is then connected a horizontal pipe ½ in. in diameter and

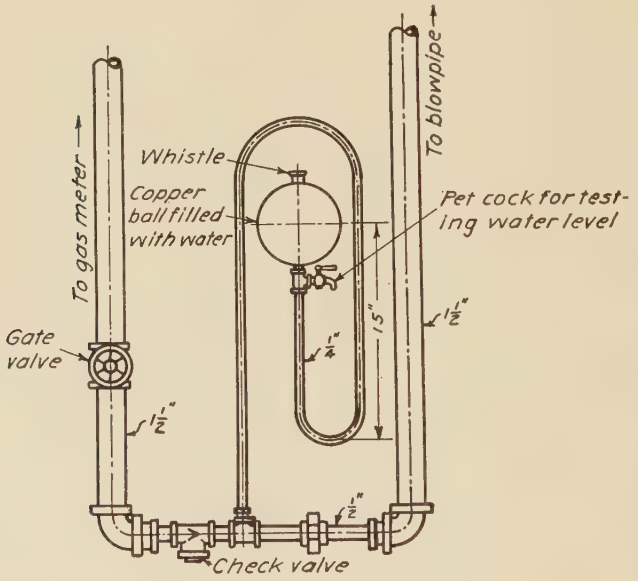


Fig. 129.

about 18 in. long. Within this pipe is inserted a check valve which prevents the flame from running back into the gas main. In addition a curved ¼-in. pipe is connected close to the check valve on the blow-pipe side. This pipe terminates in a hollow metal ball half filled with water. Should a flame from the blow-pipes run back into the gas pipes, the pressure will close the check valve, forcing the flame through the small pipe into the ball where it will be extinguished by the water. The whistle is to indicate low water.[1]

[1] *Circular* 92, U. S. Bureau of Standards.

In using the oxygen-illuminating gas flame, the reducing valve on the oxygen tank should be adjusted to give 4 or 5 lb. on the outlet side. The pressure of the oxygen is set at approximately the correct value by the valve on the tank when the reducing valve is partially open. The final adjustment of the pressure is then made by opening or closing the reducing valve. Some of these valves are so constructed that turning to the right increases the pressure. For this reason it is sometimes thought that the valve is being opened when in reality it is being closed.

The parts to be joined should be scraped clean with a lead scraper or wire brush. If this is not done, a film of oxide will form on the molten surfaces of the metal and prevent their free coalescence or fusion. In case the surfaces to be burned have been exposed to the action of electrolyte, they should be wiped with ammonia to neutralize the acid. It is well to cover the cell with a wet cloth while burning the joints so as to reduce the danger of igniting any accumulation of hydrogen and oxygen gases within the container and causing an explosion.

The melting point of lead is comparatively low, and as soon as its temperature reaches the melting point the metal will flow rapidly, and unless the fluid lead is surrounded by a ridge of cold metal, it will quickly flow away from the joint. Whenever the metal starts to flow, remove the flame and allow the work to cool before proceeding further.

In lead burning, the operator must observe carefully the condition of the metal so as to know when the lead is flowing properly; and when this condition is reached, to lift the flame immediately so that no excess melting is done. Since oxidized lead does not coalesce readily, it is preferable to hold the tip of the inner cone or blue flame on the work, although some operators use the blue flame further from the tip of the blow-pipe. The results obtained in either case depend considerably upon the skill and experience of the operator. One injunction should be carefully observed however, never jab the tip of the blow-pipe into the molten lead, and never hold the blow-pipe tip any closer to the work

than is necessary to play the tip of the inner cone of the flame on it.

When a connector is being burned to a post, the top of the post is melted first and then fused to the wall or the connector, using a rotary motion, working from the center of the post upward and outward. When additional metal is required, the deficit is supplied by melting a small rod or strip of lead into the other metal. While this is being done, the flame should be played on the stick and along the edges of the work at the same time so that the two will fuse together. A satisfactory joint cannot be made by depositing melted lead upon cold lead. The work is finally smoothed off with a file and file brush so that it has a finished appearance.

The electric outfits for lead burning are of two kinds although in operation they are essentially the same. One form consists of a portable transformer which is provided with a lamp cord and plug for connection to a lamp socket. Connections between the transformer and the work are made by two separate rubber-covered leads. One of these terminates in a heavy spring clip by which connection is made to one of the lead members which are to be joined. The other low voltage lead terminates in a carbon holder. The carbons used are especially manufactured and shaped for lead burning. The transformer is for the purpose of reducing the 100- or 220-volt lighting circuit current to a low (about 6 volts) operating current, Fig. 130.

The other and much simpler outfit consists merely of a carbon holder with connecting cable and clamp, and a carbon rod about $\frac{1}{4}$ in. in diameter, Fig. 131. The battery on which work is to be done, or any storage battery of not less than three or four cells and of sufficient current capacity, may be used for the source of current.

The operation of the electric burner is not essentially different from that of the gas burner. In one case the heating is done by a gas flame and in the other the lead is melted by the heat developed at the tip of the carbon electrode. If the current is drawn from a source other than the

battery being worked upon, the flexible lead of the carbon holder is connected to one terminal of the source of current, and the other terminal of the source of current is connected by a flexible lead to the post or connector which is to be

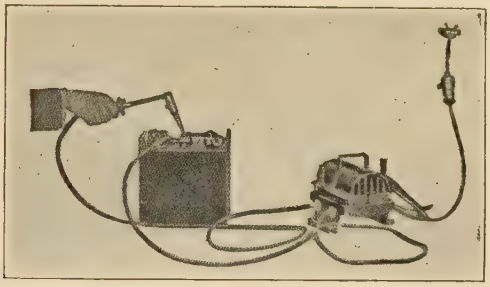


FIG. 130.

welded. The electric circuit is then completed by bringing the carbon point into contact with the lead at the point to be melted. Where the tip of the carbon touches the lead, a comparatively large current flows. The energy

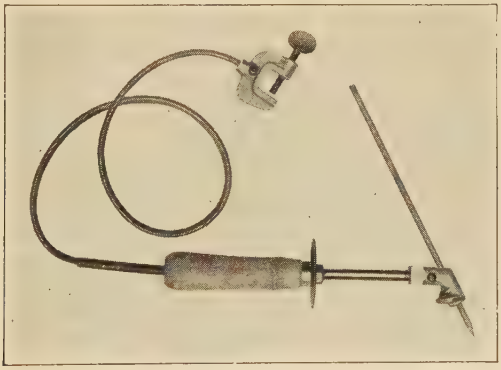


FIG. 131.

of this current is converted into heat by the resistance of the carbon tip and contact, thus producing a high temperature locally. This localized heat melts the lead over a restricted area almost instantaneously. The carbon point is moved to flow the lead where desired. No arc is drawn when the

work is being properly done, but the point of the carbon is kept barely in contact with the surface of the lead. The current may be varied somewhat by slightly increasing or decreasing the depth of the carbon point in the lead. If the operation is continued for some time, both holder and carbon will become uncomfortably hot. They may be cooled by immersing them in cold water. Furthermore, a film of lead oxide may coat the tip of the carbon and interfere with its proper operation. This defect can be remedied by filing with a coarse file or scraping with a knife. Electric lead burning is primarily adapted for joining or separating relatively small pieces.

94. Storage of Lead Cells.—Storage cells that are to be taken out of service for some time are usually stored. There are two ways of storing the battery, assembled and dismantled, known as wet and dry respectively. The kind of storage into which the battery is to be placed will be determined by the length of time it is to be out of service, the condition of the cells, and the facilities for taking care of the battery. If the battery is in good condition and will be needed in service in less than one year, and facilities are available for charging, then wet storage is preferable. To put a battery in wet storage it should first be given an equalizing charge until the specific gravity of all the cells is the same and indicates full charge. The battery is then stored in a well ventilated room on suitable benches; it is connected to a charging circuit through a high resistance such as a lamp bank so that the charging current is approximately 1 per cent of the finishing rate. As many cells of the same capacity as possible should be charged in series.

In a short time after the charge is started, the specific gravity should be taken and recorded, and then by experimenting, the charging current should be adjusted so that the specific gravity remains constant. In case it is impracticable to keep the batteries continuously on charge they can be kept in good condition by charging them at least once in two months at the normal rate until all cells are gassing freely and uniformly. At regular intervals, dis-

tilled water should be added, as necessary, to keep the electrolyte at the proper level.

To prepare a battery for dry storage, first charge fully; and when the charge is completed, empty the electrolyte from the jars and immediately refill with pure water. Let the elements remain in this about 5 hours after which they can be taken out, the separators removed, and the plates laid aside to dry. The positive plates can be removed in about 15 min., but the negative plates should remain in the water much longer. When the plates are dry, they may be stored in a dry place separately; that is, the positive and negative plates must not be placed in contact.

95. Storing the Nickel-iron Batteries.—These batteries are very easily prepared for storage. All that is necessary is to fill the cells to the proper level with electrolyte and clean them of all dirt and deposit. The batteries may then be stored in a clean dry place for an indefinite length of time without any further attention.

QUESTIONS

1. Explain how to determine the height of the electrolyte in the sealed lead-acid and nickel-iron cells.

2. Explain the operation of the Edison filler for *A*, *B*, *G*, and *T* types of cells. Why cannot this filler be used for filling the cell with electrolyte?

3. What makes a good coating for lead-acid cell terminals to protect them from corrosion?

4. Explain fully the process of removing the sediment from the bottom of the jars.

5. Explain how to determine the rate of formation of sediment.

6. What substance is used to protect the terminals and top of the nickel-iron cell?

7. Explain the operations and inspections to be made on a vehicle battery on its receipt from the manufacturer.

8. Explain in detail how to dismantle a vehicle battery.

9. Describe the proper location and construction of the battery room.

10. Which system of ventilation is preferable, pressure or suction? That is, should the foul air be forced out by locating the fan at the intake or drawn out by locating the fan at the outlet? Why?

11. What forms of jars are used for the following kinds of batteries:

(*a*) Central station

(*b*) Vehicle

(*c*) Starting and lighting?

12. May porcelain-lined iron jars be used for the preparation of electrolyte? Why?

13. How would you mix the electrolyte, by pouring the water into the acid or acid into the water? Why?

14. (*a*) If 2 quarts of acid, density 1,835, are mixed with 4 quarts of water, what will be the resulting volume?

(*b*) What will be the resulting specific gravity when the mixture has cooled?

15. It is desired to mix some electrolyte whose density shall be 1,280. How many parts of water must be used with one part of acid to produce the proper mixture?

16. Explain how to remove the top cover or covers from a sealed lead-acid cell.

17. When the elements are removed from the jar, how can they be kept from heating?

18. Is it good practice to use wood separators a second time? How can spare separators be kept in good condition?

19. How can a jar be loosened from the sealing compound in a box?

20. Against which plate is the grooved side of the separator placed? Can you give any reason for this?

21. What substances may be used for neutralizing the acid when cleaning the jar before sealing?

22. Explain in detail the process of sealing a vehicle battery.

23. What is meant by lead burning?

24. Why not bolt together the terminals of adjacent cells of vehicle batteries the same way as those of small stationary batteries?

25. Explain how the material should be prepared for burning.

26. What should be the pressure of the oxygen on the outlet side for oxygen-illuminating-gas burning?

27. What would be likely to happen if the tip of the torch became closed? How can this be prevented?

28. Describe one form of trap to prevent gas explosion in the mains.

29. (*a*) What part of the flame should be applied to the lead when burning?

(*b*) Why must the flame be used rapidly and removed frequently from the lead?

(*c*) Should the center of the post be first reduced, and then, using a rotary motion, build up the connector until flush with the top?

30. (*a*) What equipment is used for electric burning?

(*b*) What is the objection to using a large carbon? A small carbon?

(*c*) How many cells do you need in series to burn lead electrically?

31. (*a*) When are batteries put in dry storage?

(*b*) Why is dry storage better than wet storage for long storage periods?

32. (*a*) Should the battery be charged or discharged before being prepared for dry storage? Why?

(*b*) How long should the battery be charged?

(*c*) What should be the readings of the voltages? Of the specific gravity?

33. (*a*) Would you keep a record of the specific gravity of the electrolyte in each cell at the end of the charge? If so, why?

(*b*) Would you preserve the electrolyte? Why?

(*c*) How long would you wait after the electrolyte is removed before adding water?

(*d*) May heating occur? Why?

(*e*) Is it essential to get all the electrolyte out of the cell before adding water?

(*f*) What kind of water should be added?

(*g*) How high above the plates should the water stand in the cells?

(*h*) If any electrolyte is spilled on the case, how would you remove it?

34. (*a*) How long should the battery stand when filled with water? Why?

(*b*) Would the battery keep in good condition if stored with only water in it?

35. (*a*) How would you dismantle the battery after the water is emptied?

(*b*) In what kind of a place should the plates be stored?

(*c*) Should they be put on top of each other?

(*d*) Can the separators be stored and used again? How? Is it advisable?

(*e*) Can the perforated rubber sheets be stored and used again?

(*f*) Can the jars be used again?

(*g*) Will all other parts of the battery be suitable for use after storage?

36. (*a*) For wet storage purposes, compare the method of a monthly charge with that of placing the batteries on a so-called trickle charge as to efficiency and operating advantages.

(*b*) What minimum value of current should be used for trickle charge storage?

(*c*) What value of current should be used for the monthly charge method of wet storage?

CHAPTER X

DISEASES OF BATTERIES

96. General.—Storage cells, like every other human contrivance, deteriorate with time and especially with misuse. Some of the causes of deterioration are inherent in the very physical and chemical nature of the actions that take place in the cells, while others are extraneous. In either case, unless preventive measures are taken, the action of the destructive agencies may be greatly accelerated and thus greatly reduce the useful life of a battery. The most common destructive agencies may be listed under the following heads: local action and impurities; sulphation; shedding of active material; loss of capacity; short-circuits in the cells; deformation of plates.

97. Local Action.—Whenever two dissimilar substances are surrounded by an electrolyte all the elements of an electric cell are present. Invariably under such conditions a difference of potential exists between the dissimilar substances; and when they are brought into contact by a conductor, an electric current is set up which ultimately disintegrates them. Thus the rusting of iron in the presence of moist air is considered to be electrolytic rather than merely chemical. Furthermore, dissimilar substances are not absolutely essential for the establishment of a difference of potential. A difference of potential often exists between two parts of the same substance that are in different physical conditions. For instance, if one part is stressed while another is not, a difference of potential may exist between the two parts, and under suitable conditions an electric current may flow between the two parts, causing corrosion.

The formation of the elements of the modern lead storage cell is greatly accelerated by the use of forming agents.

These agents consist of substances which, when combined with lead, form a soluble lead salt. The common soluble lead salts are usually formed by a reaction between the following acids, or salts of the acids, and lead: nitric, hydrochloric, and sulphuric.

The principle of rapid formation of peroxide on the positive plate may be briefly stated as follows: The forming agent makes a layer of soluble lead salt on the surface of the lead and this, in the presence of the action of the sulphuric acid in the electrolyte, is almost immediately changed to lead sulphate. On the passage of an electric current this lead sulphate is transformed into peroxide. The forming agent which previously had formed the soluble salt is thus set free and immediately makes from the underlying lead more soluble lead salt, and the process is repeated. In order that the layer of peroxide thus formed may be tough and adhere closely to the parent lead plate the relative concentration of the forming agent and sulphuric acid must have a definite value, or else the peroxide will form at an extremely slow rate or be loosely attached to the parent plate.

The use of these forming agents introduces ions into the elements of the cell which unless removed may cause local action as explained above. It is true that there is very little likelihood that enough of the forming agent remains in the plates to give a relative concentration of the forming agent and sulphuric acid such that the forming agent will be most active. Nevertheless, a small amount of the forming agent may have quite an effect in time. The remedy for this is, of course, the careful removal of all forming agents before the plates are put into service.

While the destructive action of the forming agent is primarily confined to the positive plate, any impurities in the lead of the negative plate may also cause local action although not a destruction of the plate. Materials of which the cells are made are never absolutely pure but contain foreign substances. The common foreign substances are the metals. The action of the metals may be only temporary or continuous, depending upon their oxidiza-

bility and the stability of the oxygen compounds. The presence of metals which do not readily oxidize, such as copper, silver, and gold, together with the lead and sulphuric acid, forms little cells. Any metals that may be present in the electrolyte will, on charge, be deposited on the negative plate, and as soon as the charging voltage is removed these small cells are discharged and the energy used in charging them is wasted. Unless the metals are present in comparatively large amount their deleterious effect does not persist for many cycles of charge and discharge; for in the process of charging they are first deposited on the negative plate, and lead sulphate is gradually formed around them thus preventing their return to the electrolyte. The metals, such as iron, which form more than one compound with oxygen, have a more continuous destructive effect. The chemical reaction between iron and sulphuric acid forms ferrous sulphate. This dissolved in water according to the dissociation theory is decomposed so that the iron atom is charged with two units of positive electricity. This charged atom on discharge of the cell travels to the positive plate where it robs the peroxide plate of some oxygen after which it travels back to the negative plate and becomes converted into ferrous ion. The ion thus travels from one plate to the other carrying a charge between the two plates and thus gradually discharging them. This action is more marked on open circuit than when the cell is being charged and discharged every few hours.

A good example of local action is the self-discharge of the positive plates of a lead-acid cell. Since the positive plates consist of lead peroxide immersed in an electrolyte, all the elements of an electric cell are present. The two electrodes consist of lead and lead peroxide, and the solution of sulphuric acid is the electrolyte. Wherever the lead and lead peroxide are in contact a discharge takes place converting the body of the plate and the peroxide into lead sulphate. This discharge is due to the fact that there is a difference of potential between the lead and lead peroxide. During this discharge, an electric current flows from the lead

plate to the lead peroxide through the electrolyte, and from the lead peroxide to the lead at the point of contact. When current is taken from the cell, this sulphate on the grid of the positive plate is converted into sponge lead, and during a rest period following the formation of the sponge

FIG. 132. Examples of sulphated plates.

FIG. 133.

lead, the local action again increases the sulphate content on the positive plate.

It is thus evident that if left idle a sufficient length of time a positive plate will completely discharge itself. This is especially true of Planté plates where the peroxide is in intimate contact with the lead. The amount of lead

peroxide in contact with lead is usually a small percentage of the total amount of active material on the plate, and hence the immediate loss is only a small percentage of the total capacity of the cell. Planté plates are much more subject to osses from this cause than are paste plates.

Sulphation.—An examination of the chemical reaction formula shows that the active materials on both the negative and the positive plates are converted into lead sulphate on discharge. The formation of lead sulphate on the plates of the cells is thus a perfectly normal process. Sulphation in this sense is not a disease but is merely an indication that the cell has been discharged. If a discharged cell is left standing for some time, the sulphate becomes white, crystalline, and insoluble.

The conversion of the active material on both the positive and the negative plates into the insoluble form of lead sulphate is greatly aggravated when the plates are left in a discharged condition for a considerable period of time and also when the plates are exposed to the air. If the level of the electrolyte is not kept above the top of the plates by the frequent addition of distilled water, the exposed portion of the active material soon becomes converted into hard crystalline sulphate. Among the more immediate deleterious effects of sulphation are the increase in the internal resistance of the cells, the loosening of the active material from the grid, and the decrease in capacity of the cells. The resistance is increased by the formation of the sulphate between the peroxide and the lead grid. The decrease in capacity is due to the difficulty with which the sulphate is broken down and also the incrusting of the separate particles of the peroxide by the sulphate. Figures 132 and 133 show sulphated plates.

The more common symptoms of sulphation are: Continued low specific gravity; low open circuit voltage; loss of capacity; a low charging current under normal charging voltage; and light color of both groups of plates.

98. Regeneration of Sulphated Plates.—The best plan to prevent the formation of the insoluble sulphate is to keep

the cells fully charged and to give an occasional overcharge. This is explained under *charging*.

If the sulphate has been permitted to form, it can often be reconverted into active material by successive prolonged charges and discharges at a low rate. If the plates are badly sulphated, the best method of regeneration is to replace the electrolyte with distilled water and charge the battery. If during the charge the specific gravity reaches 1,150, the electrolyte is again replaced by water and the charge is continued until the sulphate is reduced. When the process is completed, the old electrolyte is removed and the cells are filled with fresh electrolyte of proper specific gravity. The temperature of the pilot cells should be taken at regular intervals throughout the period of charge and the specific gravity of each cell should be read and, after correcting for temperature, recorded at intervals of 4 to 6 hours. The level of the electrolyte should be maintained constant by the addition of water after each reading of specific gravity which should not be permitted to rise above 1,150.

The temperature of the cells during the process of charging should not be permitted to rise above 110 deg. Fahr. (43 deg. Cent.). In case the temperature rises above this limit, the charging current must be reduced or temporarily discontinued.

99. Shedding of Active Material.—The shedding of active material in some cases is a perfectly normal process in the operation of the cell, while in other cases it may be the result of improper use. Lead storage cell plates are of two kinds or types, the types being determined by the process employed in forming the active material. The active material of Planté plates is formed from metallic lead and not from its salts which have been pasted into the interstices of a lead grid. Such a positive plate when first formed has just enough active material to give its rated ampere-hour capacity. When such a plate is operated at high rates of charge and discharge, the rapid evolution of gas loosens and dislodges peroxide which accumulates

at the bottom of the jar as mud. After several cycles of charge and discharge, the original material is converted into a dense layer of peroxide which firmly adheres to the lead grid. The capacity of such plates at the high rate of working is perhaps increased in spite of the loss of a portion of the original active material.

If a new, fresh, Planté plate be put in service requiring low rates of charge and discharge, it will also undergo a change but not so marked as when in heavy service. At low rates of charge, diffusion of the electrolyte is quite complete, and the interstices are filled with peroxide, increasing the capacity of the plate.

In either case the plates adapt themselves to the conditions of service. They increase in capacity in harmony with the demands to which they are subjected. If, however, plates that have been used on one kind of service are subjected to the other kind of service, it will take some time before they become adjusted to the new conditions. Plates that have been used at high rates of charge and discharge will not have the same capacity at low rates as a similar set of plates used at low rates although no damage will result by the transfer. On the other hand, plates which have become adapted to low rate service cannot be suddenly subjected to service requiring high charge and discharge rates without shedding an excessive amount of active material. The transfer of Planté plates from a low rate to a high rate should be gradual.

Negative plates of the Planté type are not subject to damage from this source although they do lose capacity during the first 100 cycles or so of charge and discharge. This loss of capacity is due to an increase in the size of the grains of the active material which are not completely reconverted on charge. In other words, the porosity is decreased.

100. Loss of Capacity.—Some of the causes for the loss of capacity have already been discussed. Referring to Art. 58 we learn that the ampere-hour capacity ultimately depends upon the number and area of plates and the thick-

ness of the active material. This theoretical capacity is not the one usually referred to in practice. It has also been shown that the ampere-hour capacity varies with rates of charge and discharge, the capacity on intermittent discharge being greater than on continuous discharge at corresponding rates.

Both the lead-acid and the nickel-iron cells lose capacity on standing idle. The time rate of loss is shown in Fig. 35 in which curve *A* is for the nickel-iron type and curve *B* for the lead-acid type. This decrease in capacity of the lead-acid cell is, perhaps, due to local discharge and the formation of insoluble sulphate within the pores of the plates. In the nickel-iron cell a slow oxidation of the iron takes place which is not so easily reduced on charge as the oxide formed by the discharge of the cell.

The capacity of both types of cells also decreases with a decrease in temperature. This loss of capacity is regained when the cells are again warmed.

The ordinary loss of capacity is due to a decrease in the amount of active material, and accordingly the rate of decrease varies with the character and type of plates. In general all types of positive plates increase in capacity for a time when first put into service. The increase in capacity of paste plates is due to an increase in the porosity and softening of the active material. Thus they acquire a maximum capacity in use; and after this maximum capacity has been acquired, there is a continuous decrease in capacity throughout their period of usefulness. The positive plates of the Planté type increase in capacity for a period of use by the formation of active material out of the lead plate. Usually, when the active material of Planté positive plates has disintegrated, the lead grid is slowly converted into peroxide and finally nothing but a mere skeleton is left, and this has very little capacity. Before the plates have reached this condition, they should be discarded.

The loss of capacity of the Planté negative plates is not so much due to the shedding of active material as to the formation of large grains of lead which are not completely

transformed into sulphate during discharge. New formation of lead takes place on the outside, and thus the plate gradually grows denser and the capacity decreases continually while in service. In order that Planté negative plates may have sufficient capacity for reasonable length of service, they are made to have approximately 100 per cent excess capacity when new. This excess of capacity is rapidly lost during the first months of service so that at the end of the first year the excess will not be over 25

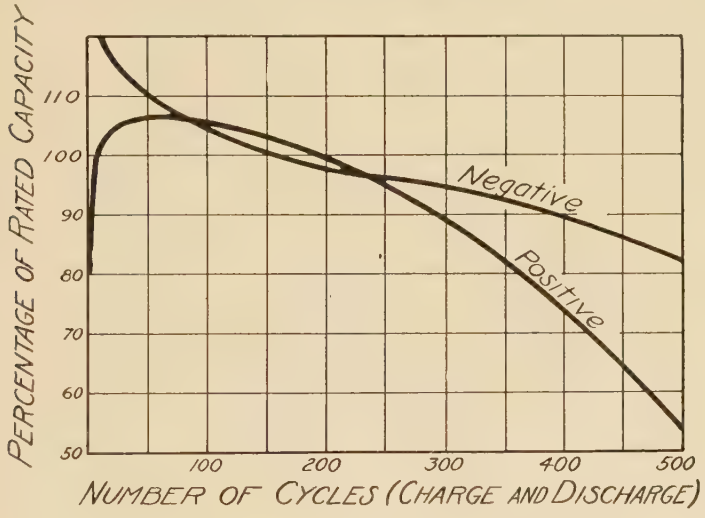


FIG. 134.

per cent. Figure 134 shows the change in capacity of light Planté plates with number of cycles charge and discharge.

Negative Planté plates that have lost their capacity can be regenerated by converting the active material to lead peroxide and then back to lead again. It is not a good plan to use the regular positives as electrodes for reversing the negatives unless they are in poor condition and will be discarded after use. Old positives may be used as electrodes when this method of regeneration is to be used.

101. Short-circuits.—If the positive and negative plates of a cell come in contact, a local circuit is established

which not only discharges the cell but may damage the plates. Separators of wood and rubber are used in batteries to prevent plates of opposite polarity from coming into contact. If the sediment that accumulates at the bottom is not removed often enough, it likewise may reach the plates and short-circuit them. Close inspection is the only prevention for short-circuits in cells. This inspection is comparatively easy when the plates are in small glass jars, but in the sealed cells and in the very large cells with lead lined tanks the necessary inspection to prevent short-circuits is much more difficult. There are several symptoms which indicate a short-circuit: A low specific gravity as compared to the rest of the cells; a lower voltage on charge than the other cells of the battery; lack of capacity and low voltage on discharge; heating; lack of gassing on charge; and poor color of the plates.

102. Deformation of Plates.—Lead is an inelastic material. By this is meant that when a plate or rod of lead is bent it will not return to its original condition, when the bending force is removed, but will remain distorted. The bending or distortion of lead plates is produced by unbalanced forces, that is, forces whose effect is not counteracted. Thus when the active material on a plate is undergoing a change, forces produced on one side are not counteracted by forces on the other side. The plate will be bent or "buckled," as such deformation is usually called. On account of the inelasticity of lead, the plate will remain bent.

These unbalanced forces may be produced in several different ways, such as (*a*) unequal heating; (*b*) unsymmetrical charging; (*c*) excessive rates of charge and overcharge; (*d*) impurities and local discharge; (*e*) unequal distribution of active material on both sides of the plates; (*f*) sulphation and perhaps other causes not so obvious.

The relative influences of the above causes are not easily determined as they will vary with the individual cells as well as with the kind or type of cell; their general effect in producing buckling or distortion can, however, be readily understood.

(*a*) *Unequal Heating.*—The temperature of the elements of a storage cell rises on charge as is disclosed by the temperature curve, Fig. 52. If the diffusion of the electrolyte is rapid so that the temperature is uniform throughout the cell, no distortion of the plates will take place merely because the temperature changes. If, however, the diffusion of the electrolyte is slow, then certain parts of the plates will become warmer than others and the consequent forces of expansion will distort the plates. As the plates undergo cycles of heating and cooling, the distortion, due to this cause, may become appreciable although it will seldom be serious. It is not temperature changes alone, such as are likely to occur in a storage cell, that produce buckling, but non-uniform distribution of temperature over the whole plate.

(*b*) *Unsymmetrical Charging and Discharging.*—On the positive plate the lead peroxide and on the negative plate the sponge lead are converted into lead sulphate on discharge, and vice versa on charge. The densities of the lead compounds that are involved in the operation of the cell are approximately as follows:

	Density
Metallic lead	11.4
Lead peroxide, hydrated	7.4
Lead peroxide, dry	9.4
Lead sulphate	6.2
Litharge	9.3
Red lead	8.9

The lead peroxide is denser than the lead sulphate, and hence when the peroxide is converted into sulphate its volume is greater than the volume of the peroxide from which it was formed. This increase in volume produces pressure which, unless it is counterbalanced, distorts the plates. For example, if the discharge is not uniform over the surface and throughout the active material of the plates, the increase in the lead sulphate at those points which are most rapidly undergoing transformation produces unbalanced forces which cause buckling. Since it is practically impossible to so place the plates that the rate of trans-

formation is uniform throughout the active material, distortion due to this cause is bound to result.

(*c*) *Excessive Rates of Charge and Discharge and Overcharge.*—These, like heating, in themselves could not produce buckling, but on account of the fact that prolonged and excessive rates of charge and discharge cause heating and non-symmetrical transformation of the active material, unbalanced forces are produced which cause deformation of the plates. Probably the treatment that will most quickly cause buckling is a repetition of overcharge, especially at low rates. This results in an increase of the active material, producing expansion with resulting buckling. An overcharge which produces metallic lead is another cause of buckling. The engineer of a large storage battery company reports that most trouble from buckling is experienced in classes of service where the rates of charge and discharge are low.

(*d*) *Impurities and Local Discharge.*—The character of the action of the impurities will depend on the kind and amount of the impurity present. The presence of metals will produce local discharge as already explained. The action of the impurities is accelerated by heating and, hence, this is likewise a possible cause of buckling. The influence of local discharge in producing deformation of plates can be easily understood when the changes that take place under such conditions are considered. In local discharge only certain parts or spots of the active material are converted into lead sulphate. As the lead sulphate occupies more space than the peroxide from which it was formed and as it is not uniformly distributed over the plates, the resulting unbalanced forces cause bending and distortion.

(*e*) *Unequal Distribution of Active Material.*—Some distortion may be due to defective forming of the plates. If there is more active material on one side of the plate than on the other, then the changes in volume that ta ntaalce on charge and discharge will stress one side more kehp the other and the plate will buckle.

Another change in the size of Planté plates takes place during the forming process. This is due to the formation of lead peroxide from metallic lead by the aid of forming agents which are finally eliminated. The greater volume of the peroxide than the lead from which it is formed causes a stretching or lengthening of the plates along the ribs. This effect is more marked when the peroxide is dense and firmly imbedded in the lead support. This effect may become manifest in the service if all of the forming agent has not been removed so that on subsequent cycles of charge and discharge more peroxide is formed.

The negative plates that are formed from litharge and red lead are much less affected by changes in the density of the active material than the positive plates. The sponge lead is denser than the litharge from which it is formed. Consequently, there is a shrinkage during the forming period. On discharge, when the sponge lead is converted into lead sulphate, there is an increase in volume, but owing to the porosity of the sponge lead the resulting forces of expansion are not so destructive. Plates that have been used at high rates of charge and discharge when put in service at low rates are liable to buckle. The low charging current produces much compacted active material near the supporting ribs. This on discharge is converted into sulphate, and the resulting pressure distorts the plate.

(*f*) *Sulphation.*—The formation of hard crystalline sulphate is likewise a cause of buckling. If such a condition prevails, the change of volume is a maximum, and distortion of the plates is inevitable.

From the foregoing it is evident that the main cause of buckling and other deformation is the change in volume that accompanies the conversion of active material. This cause may be aggravated by improper charging methods, heating, and misuse. Any treatment that will produce more than the normal amount of imbedded active material will cause deformation or fracture of the plates. The forces of expansion may be so great as to burst the containing jar.

103. Diagnosis of Storage Battery Troubles.—Before a correction can be made, or a remedy can be applied for any disorder, the cause of the disorder must be located. The discovery of the cause of some defect or improper condition in a storage battery is sometimes difficult for, just as in human ailments, the symptoms of different disorders are the same, and experience is necessary to locate the correct cause.

In the foregoing discussion of storage battery diseases it is shown that the most common symptoms of trouble are low voltage, low capacity, and low density of electrolyte. These are the most obvious symptoms; nevertheless, they may be due to one of several, or a combination of several, causes. For instance, low voltage may be due to merely a discharged condition; low capacity may be due to sulphation or under-charge, loss of active material, or any number of other causes; low density may also be due to discharged condition or short-circuit in the cells. That is, if there is a short-circuit in the cell, the density of the electrolyte of that particular cell will remain low on charge while the density of the electrolyte in the other cells rises.

It is thus obvious that the exact cause of the poor operation of a storage cell cannot always be located by merely making some simple tests. It will usually be necessary to know the conditions of service and the rates of charge and discharge at which the cell has been operating before a correct diagnosis can be made. The most common cause of storage battery troubles is continued under-charge. In other words, if the cell is charged at a low rate for a certain interval and discharged at a high rate for the same interval, it will seldom be fully charged and soon many of the defects enumerated at the beginning of this chapter will become manifest. When comparatively new plates show low capacity, are sulphated, begin to buckle, and shed active material, operating conditions are likely to be at fault. The cells have most likely been discharged at high rates and charged at low rates with the result that they are in a chronic state of discharge. Most battery troubles can

be obviated if the cells are kept fully charged, and occasionally over-charged. For detailed instructions of charging, etc. see chapter on maintenance of storage cells.

RECAPITULATION

1. The most common *destructive agencies* of storage batteries are local action, sulphation, shedding of active material, loss of capacity, short-circuits in the cells, and deformation of plates.

2. By *local action* is meant the action that takes place within the cell when some dissimilar substances, usually one of the metals, are present and in contact in the electrolyte. The presence of this foreign substance together with the elements of the cell produces a local current which gradually discharges the plates. A good example of local action is the self-discharge of the positive plates of the lead-acid cell.

3. By *sulphation* is meant the forming or conversion of the lead sulphate into a hard crystalline form; that is, into a form which is not readily broken down on charge. If plates are left in a discharged condition for a length of time, the sulphate gradually converts into this hard crystalline form. Likewise, if plates are left exposed to the air, sulphation takes place. The more common symptoms of sulphation are: Continued low specific gravity, low open circuit voltage, loss of capacity, low charging current under normal charging voltage, and light color of both groups of plates.

4. Badly *sulphated cells* may often be *regenerated* by replacing the electrolyte with pure water and then charging them until the sulphate on the inner side of the plates is reduced.

5. By *shedding of active material* is meant the falling off of the loose peroxide. The lead peroxide is not an integral part of the lead plate but is merely cemented to it. The lead peroxide gradually falls off with successive periods of charge and discharge. Excessively high rates of charge with the rapid acceleration of gas often increase the rate at which this active material is thrown off.

6. By *loss of capacity* is meant the gradual decrease in the number of ampere-hours that a storage cell is capable of discharging on successive cycles of charge and discharge. The loss of capacity is due to various causes. The ordinary loss of capacity is due to a decrease in the amount of active material on the plates. Both the lead-acid and the nickel-iron cells lose capacity if left standing idle, when the temperature decreases, and on excessive rates of discharge.

7. By *short-circuit* is meant the connecting of opposite plates within a cell by a conductor of extremely low resistance. Short-circuits may be due to several causes: Buckling, the lodging of some conducting material

between the plates, and the building of lead mass or trees between them or around the separators. The failure of the density of the electrolyte to increase on charge and loss of specific gravity as compared with other cells of the battery are good indications of short-circuits in the cell.

8. The *deformation of plates commonly called buckling* is due to many causes. The more common ones are as follows: Unequal heating; unsymmetrical charging; prolonged excessive rates of charge which cause heating; overcharging, especially at low rates; local discharge; impurities and unequal distribution of active material on both sides of the plates. The main cause of buckling is the change in volume that accompanies the conversion of active material. This cause may be aggravated by improper charging methods, heating, and misuse.

9. By *diagnosis of storage battery trouble* is meant the determining of the cause of the trouble from its symptoms. Most battery troubles can be obviated if the cells are examined regularly and are kept fully charged.

QUESTIONS

1. Name the most common destructive agencies of storage batteries.

2. Explain how local action causes a deterioration of the plates.

3. What substances are likely to be present in a cell and cause local action?

4. Explain the continuous destructive effect of iron in a cell.

5. What is meant by sulphation in the harmful sense of the term?

6. What are the common symptoms of a sulphated battery?

7. Explain how sulphated plates may be regenerated.

8. Explain what is meant by the shedding of active material and its causes. Do the negative plates shed active material to the extent that positive plates do?

9. Is it safe to transfer Planté plates from low-rate service to high-rate service? Explain.

10. What effect does standing idle have upon the capacity of storage cells?

11. Which of the two kinds of Planté plates loses capacity at the higher rate, the negative or the positive? Explain why.

12. Which type of Planté plate will maintain its capacity for a longer period?

13. Suppose you have been charging a cell for some time and find that the density of the electrolyte remains low. What is the probable cause? Explain.

14. Enumerate the common causes of buckling.

15. Suppose the active material on a plate is thicker on one side than on the other. Is such a plate liable to buckle and, if so, why?

16. Explain why local discharge may cause buckling.

17. Explain why negative plates formed from litharge and red lead are much less liable to buckle than positive plates.

18. Is it possible to locate the trouble on a storage battery from the symptoms alone? Explain.

19. When comparatively new plates show loss of capacity and are sulphated, what is likely to be the trouble?

20. How can most battery troubles be avoided?

CHAPTER XI

COMMERCIAL BATTERIES AND THEIR USES

104. Names and Distinguishing Characteristics.—The names applied to the plates and complete cells of the lead-acid type usually have reference to process of manufacture, structural characteristics, and use.

The designations that have reference to processes of plate formation are Planté and Faure, the names of two men who first used the principles now associated with their names.

Such names as "Tudor," "Gould," "Manchester," "shelf," "diamond grid," "box," etc. refer to some structural characteristic, while some of the more common designations based on use are "vehicle," "train lighting," "farm lighting," "submarine," "radio," etc. While these names are convenient trade and service designations, and while plates so designated are distinguished by some characteristic feature of construction, assembly, or mounting, the names have no significance with reference to the fundamental principles of operation, care, and maintenance.

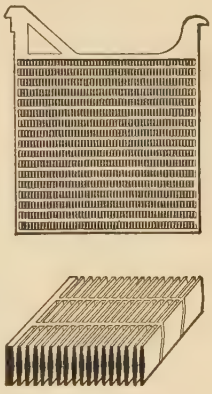


FIG. 135.—Tudor positive and section.

105. Planté and Faure Plates.—As already explained, the terms Planté and Faure (pasted), refer to processes of manufacture. The active material on the Planté plate is formed out of the plate itself, while the active material of the pasted plates is formed from lead salts that have been pasted into pockets of a lead-antimony grid. As a result of this difference in the process of formation, the plates

have different charge and discharge characteristics which make each type best suited for a particular kind of service. The large surface Planté plates are better suited for service

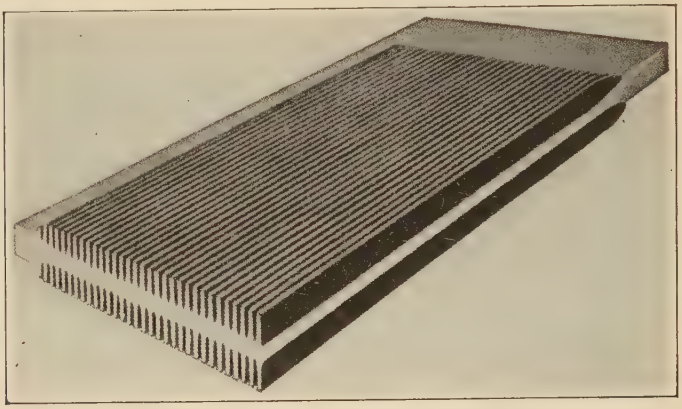


Fig. 136.

requiring high discharge rates, but as they are more expensive and suffer more from local action than paste plates, the latter are used more extensively for all classes of service except vehicle service.

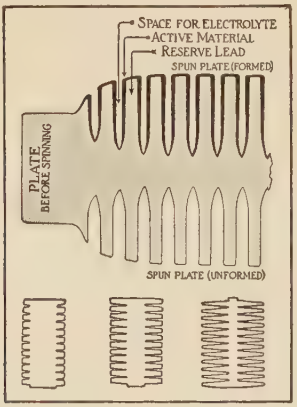


Fig. 137.

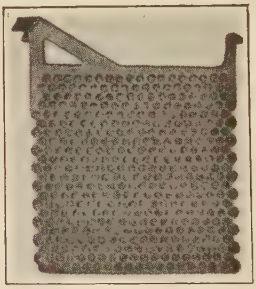


Fig. 138.

106. Structural Characteristics.—The structural characteristics that are designated by special names are shown in Figs. 135 to 141 inclusive.

The Tudor plate shown in Fig. 135 is a Planté type, cellular casting of pure lead, the wedge-shaped ribs giving large surface and permitting comparatively free circulation of the electrolyte. The rather open structure permits of the transformation of active material from one form to another without undue crowding and consequent development of distorting forces. It is claimed that this form of construction reduces buckling to a minimum.

Another and popular form of Planté plate is the Gould shown in Fig. 136. This in some respects resembles the Tudor plate, but the large surface is produced by a process called "spinning," or swaging, instead of casting. A blank

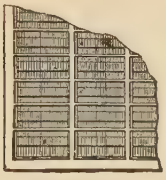


Fig. 139.

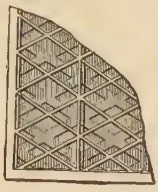


Fig. 140.

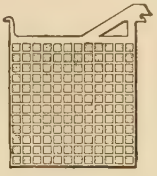


Fig. 141.

of pure rolled lead is run between mandrels or rolls on which are discs separated by washers. The rapidly revolving rolls press evenly against the plate, causing the lead displaced by the spinning discs to flow into the spaces between. The successive steps are shown in Fig. 137. Both positive and negative Planté plates are manufactured by this process. The large open grooves give good circulation of electrolyte which is essential for rapid diffusion on high discharge and charge currents.

The Planté type plates of the National Storage Battery are formed in a similar manner.

A composite type of plate known as "Manchester" is shown in Fig. 138. This consists of a lead-antimony blank with a number of symmetrically spaced round holes. The active material is formed from spiral coils of corrugated lead ribbon pressed into the holes. The amount of active material is then determined by the amount of lead ribbon used. When this is exhausted, no more is formed

from the supporting web as in the two other types just described. Such a plate is rugged although it does not maintain relatively so high a capacity as plates on which the active material is constantly renewed from the body of the plate.

The terms "shelf type," "diamond grid," and "box type" are used to distinguish different forms of pasted plates. The first parts of these terms refer to the shape of the pockets into which the active material is compressed. The supporting grid of the box negative is cast in halves, the outside of each consisting of a very thin and perforated sheet of lead. The active material is placed in the rectangular pocket of one half of the grid and the other half is then placed over this, thus "boxing in" the active material. The two parts are then riveted together. These three types are shown in Figs. 139, 140, and 141.

The term "ironclad" is a trade name applied by the Electric Storage Battery Co. to one form of its pasted plate batteries. The plate consists of lead-antimony bars at the top and bottom connected by vertical rods of the same material. These vertical rods are surrounded by the active material encased in horizontally laminated hard rubber tubes. These tubes retain the active material in place and also serve as separators. There is no iron in these cells as the name might suggest. The ironclad battery is specially designed for service where it is subjected to jars and vibrations, as on vehicles.

Another trade name in quite common use, and which likewise is a suggestive misnomer, is the chloride accumulator. This name was derived from a former process of manufacture. The chloride negative was made by casting a lead grid around pellets of lead chloride which were then converted into sponge lead by the elimination of the chlorine. There was no chlorine present in the finished plate, and the process of manufacture is no longer employed.

107. Use-controlling Characteristics.—As storage cells are not primary, or original, sources of energy, considerations other than economy in the generation of energy

are controlling in their use. The two characteristics of a storage battery that usually determine its use in place of some other transformer or converter of energy are:

First.—Its ability to keep energy in storage or reserve; that is, its ability to receive energy at one time and to deliver it at some other time on demand. The receipt and delivery of energy by nearly all other transforming devices are simultaneous.

Second.—The rate at which energy is stored in a storage battery bears no necessary relation to the rate at which it can be delivered; for other transforming devices, neglecting internal losses, the rates of receipt and delivery are the same.

It is the ability of a storage battery to receive energy at a low rate and to deliver it at a high rate on demand that makes it superior to any other form of energy converter for many applications.

Among other characteristics of the storage battery that are peculiar to it and that account for its wide use are portability, constancy of voltage and current, divisibility into small units, and possibility of changing voltage and current by suitable groupings of the cells.

108. Applications of Storage Batteries.—Storage batteries are used for so many different purposes that mention can be made of only a few of them. A few years ago the main application of storage batteries was as a reserve power supply in connection with central electric station service. This application is still important, but in so far as the manufacture of storage cells is concerned, it is relatively less important than the making of small units for automobiles, electric vehicles, isolated lighting plants, radio communication, and other uses requiring small quantities of power.

109. Emergency Service.—One of the indispensable requirements of electric central station service is continuous or uninterrupted supply of power. To maintain such service auxiliary apparatus must be provided and maintained in a condition to take up the load immediately in case the regular equipment is crippled. To secure this

continuity of service would in some instances require a duplication of much of the equipment at a prohibitive expense. Such emergencies can quite often be met by the installation of a storage battery of considerably smaller normal capacity than the continuous capacity of the generating equipment.

Another important emergency service for which storage batteries are installed is auxiliary lighting in central stations. In such an installation the storage battery is automatically connected to the lighting circuit as soon as the regular

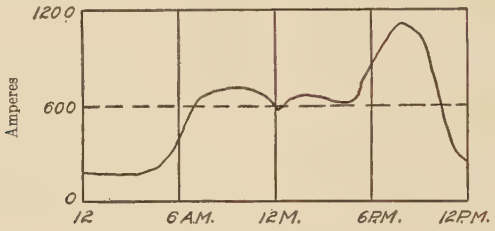


Fig. 145.

Fig. 142.—A load curve.

lighting system is disabled. No matter what the emergency, as long as the battery and the lighting circuits are not destroyed, light is always available. Such installations might be advantageous in theaters, hospitals, and other places where the lives of people are endangered by the interruption of the electric energy supply from the outside.

110. Auxiliary Power Service.—The use of storage batteries to supply power over comparatively long periods while the generating apparatus is idle, as was customary a few years ago, is, with the exception of the farm lighting units, on the decline. They are, however, used in many installations to supplement and equalize the regular generating equipment output. Such use is especially beneficial in connection with power plants whose load is subject to rapid and great fluctuations as indicated in Fig. 142. This load curve shows that between 12 a.m. and 7 a.m. the load current changed from about 180 to 600 amp. It remained approximately constant until about 6 p.m. when it began

to increase and reached a maximum at about 8 p.m. From 12 a.m. to 6 p.m. a 600-amp. generator is large enough to carry the load, but it is too small to carry the load from 6 p.m. to 10 p.m. Either another generator must be operated during this interval or else the output of the generator must be supplemented by a storage battery. For this purpose a battery is floated on the line, and its voltage is regulated by end cells or some form of booster.

The battery is discharged during the heavy load period, and is charged during the hours of lighter load. With the proper management it is possible to have the generating equipment operating at its maximum efficiency at all times and even to shut down the plant altogether during the hours when the load is extremely light, using the battery as the only source of supply at this time. As there is considerable loss in changing electrical energy into chemical energy and then back again, the efficiency will not exceed 75 per cent for this class of service.

The changes in the load curve shown above are comparatively slow. There are other cases, such as street railway service, where the fluctuations are rapid and come at short intervals of time. Under such conditions an auxiliary storage battery will equalize the load on the main generator in exactly the same way. The conditions of service are somewhat different, but the principles of equalizing the load on the generator are the same.

111. Voltage Regulation.—In many installations where both motors and lamps are supplied by the same generator, any sudden changes in the power load are likely to cause voltage fluctuations which adversely affect the operation of the lamps. To remedy such an undesirable condition it is customary to connect a storage battery in parallel with the generator as shown diagrammatically in Fig. 143. The voltage at both the lamps and motors is maintained constant by the combined action of booster and battery. The booster is a small d-c. low voltage generator of comparatively large current capacity and is driven by a shunt motor. The booster is provided with two sets of field coils, one set

arranged for the full voltage and connected across the line with a regulating rheostat in series with it. This is called the shunt field. The other set is connected in series with the load and is called the series field. The magnetizing action of the series winding is opposite to that of the shunt winding. The booster is driven by a motor from the mains, at constant speed. With no current in the series fields the shunt windings are adjusted so that the proper charging current flows into the battery. When

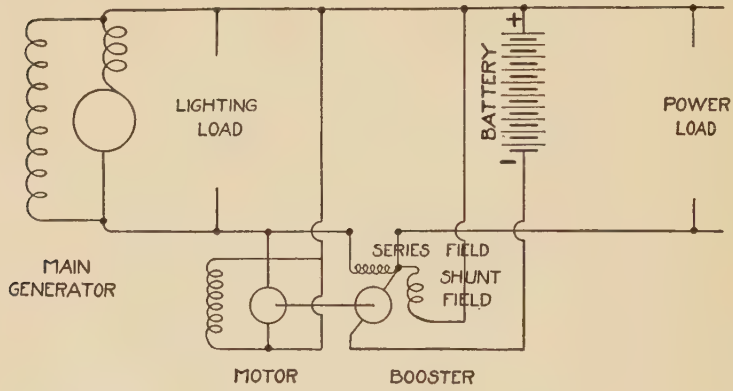


Fig. 143.

the motor load increases so that the current flows through the series field, the voltage of the booster armature is lowered or even reversed in direction since the series winding tends to produce a field in a reverse direction from that produced by the shunt winding. The result is that the battery discharges at a rate which is determined altogether by the design of the system, the booster, and the magnitude of the current flowing in the series field. It is evident that when the battery is discharging through the booster armature, the latter is running as a motor and its speed would rise indefinitely were it not for the fact that a shunt motor which is direct-connected to the shaft inherently becomes a generator when its speed is increased a few per cent and supplies current to the mains, in parallel with the main generator.

Another use of storage batteries for voltage regulation is in connection with three-wire systems of direct-current distribution at rotary converter substations. This is diagrammatically shown in Fig. 144. This shows two rotary converters each supplying current to a three-wire system, the two systems being interconnected. One set of the rotaries may supply current at 230 volts to the customers close to the substation and the other may be

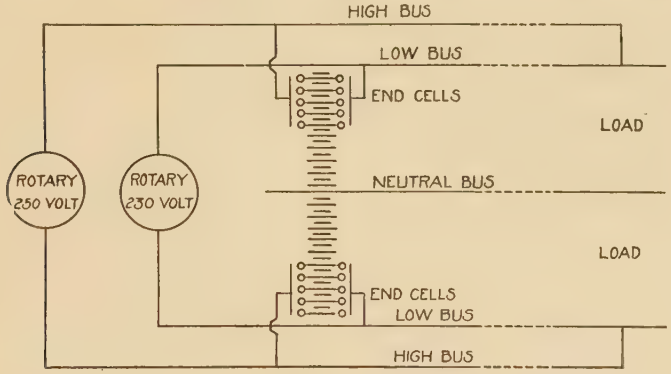


Fig. 144.

operated at 250 or 260 volts and be used for supplying current through feeders to more remote customers. The former is connected to what is termed the low bus and the latter to the high bus. The entire distribution system is connected to form a network at all times. A battery may be floating on both the low and the high bus at the same time if two sets of end-cell switches are installed on each side of the neutral. The neutral bus is connected to the center of the transformer secondary windings as well as to the center of the battery and to the ground.

112. Vehicle Batteries.—Another extended application of storage batteries is to furnish the motive power for trucks, mine locomotives, passenger automobiles, and the like.

Vehicle batteries are essentially the same as others, but in order that the battery may occupy a small space and still have high capacity the plates are thin, closely pressed

together, and nearly fill the jars which are sealed. The cells and crates are compactly assembled and mounted on the vehicle which they are to propel.

113. Automobile Starting and Lighting.—The use of storage batteries on automobiles and trucks for supplying current for the lights, starting motor, and ignition circuits is one of their most important applications. These batteries are also distinguished by compact construction and assembly. The battery usually consists of 3, 6, or 12 cells so as to supply current at 6, 12, or 24 volts. The ampere-hour capacity varies with the make of automobile, but it is seldom above 150 ampere-hours.

FIG. 145.

These batteries are invariably charged by a generator driven by the engine of the vehicle. An automobile starting and lighting battery is shown in Fig. 145.

114. Train-lighting Batteries.—The storage battery is an essential component of all train-lighting systems of which there are three types: Batteries only, batteries and axis-driven generators, and batteries in conjunction with a steam-driven generator located in the baggage car or on the engine.

Batteries for train lighting, like all portable forms, must be constructed to withstand jarring and rough usage. The cell tanks or jars of train-lighting batteries are of two kinds: Lead-lined wooden tanks and rubber jars set in wooden trays.

The lead-lined tank consists of a heavy oak box lined with sheet lead the joints of which have been "burned" to prevent the leakage of electrolyte. To prevent this lead lining from short-circuiting the plates, a layer of heavy glass plates is fitted inside of this lead lining. To prevent splashing of electrolyte the cells are sealed in the same manner as vehicle batteries.

The rubber jar is much cheaper and of more simple construction. The rubber jars are usually reinforced to a depth of about 2 in. around the top where the breakage is most likely to occur.

115. Farm-lighting Batteries.—Lead-acid batteries for farm-lighting units are usually of the glass jar isolated-plant type. They are installed in connection with a generator and gasoline engine of suitable size which is determined by the amount of power needed. For isolated farm plants the power rating of the engine is seldom above 5 horsepower although any desired size can be obtained. Suitable generators with voltages from 12 to 220 volts either belt driven or direct connected are also available.

The nickel-iron-alkaline cell is also used in isolated plants, but owing to the lower voltage a greater number of cells is needed to give the same voltage.

116. Selection of Proper Size of Farm-lighting Battery.—In selecting a battery two factors must be kept in mind, voltage and ampere-hour capacity. The voltage is determined by the number of cells connected in series and is entirely independent of the size or ampere-hour capacity of individual cells. The number of cells to be used is determined by the voltage limits permissible which vary with the conditions of installation. As the voltage of cells decreases on discharge, and as there is always some voltage drop in the wires from the battery to the lamps, it is a good plan to install one or more cells than would be required if the voltage of each cell remained at 2.1 volts. The number of cells used for different voltages differs somewhat among different companies. Table IX, however, gives representative results:

TABLE IX.—NO. OF CELLS REQUIRED

Voltage	Lead-acid type	Nickel-iron-alkaline type
30	16	24 to 27
65	32 to 34	60 not common
100	52 to 54	90 not common
110	56 to 60	94 to 98

The size or ampere-hour capacity of the individual cells is determined by the size, number of lamps, and other apparatus that are to be operated by the battery at one time, and the continuous length of one such period of operation. The size of a 110-volt battery for a particular installation can be determined approximately by the method outlined in the following example. It is assumed that the battery will be charged at any time during the day convenient to operate the generator.

EXAMPLE

What should be the ampere-hour rating of a battery to operate lamps as follows:

Ten 25-watt tungsten lamps from 5 to 10 o'clock.
Ten 40-watt tungsten lamps from 5 to 10 o'clock.
Three 10-watt tungsten lamps from 10 to 6 o'clock.
Eight 25-watt tungsten lamps from 6 to 8 o'clock.

SOLUTION

A 25-watt 110-volt tungsten lamp takes about 0.25 amp., a 40-watt lamp about 0.4 amp., and a 10-watt lamp about 0.1 amp. The ampere-hour consumption is, therefore, as follows:

$10 \times 0.25 \times 5 =$	12.5 ampere-hours
$10 \times 0.4 \times 5 =$	20 ampere-hours
$3 \times 0.1 \times 8 =$	2.4 ampere-hours
$8 \times 0.25 \times 2 =$	4.0 ampere-hours
Total	38.9 or 40 ampere-hours

The maximum discharge rate is $10 \times 0.25 + 10 \times 0.4 = 6.5$ amp. Therefore, a 40-ampere-hour battery with a discharge of 5 amp. for an 8-hour period should prove satisfactory if carefully maintained. As it is seldom possible to give a farm-lighting battery the care necessary to maintain it fully charged and in first-class condition, it is better to select one of 75 to 100 per cent greater capacity than indicated by the load conditions. The greater the interval between charging periods, the greater must the capacity be. Thus instead of a battery of 40-ampere-hour capacity one of 60 to 80 ampere-hours would give more reliable service if charged daily; but if the battery is to be charged only twice a week, one of 160 ampere-hours capacity would be preferable. It is, therefore, better to install a battery of considerable reserve capacity which will not fail in emergencies.

The maintenance of farm-lighting batteries does not differ in any respect from the battery maintenance in other service.

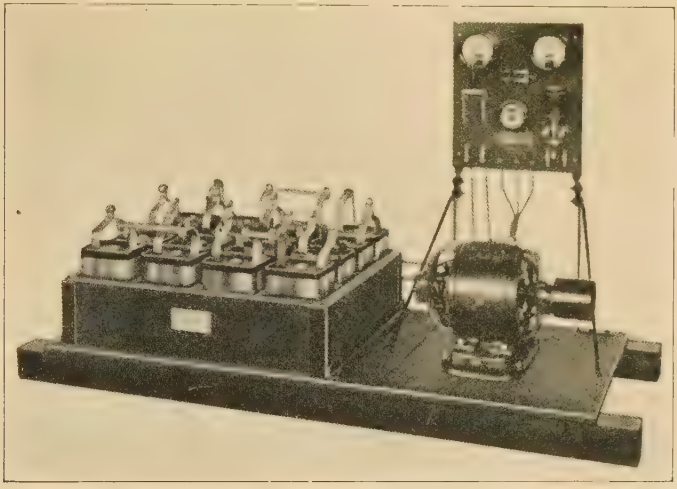


FIG. 146.

A typical installation of a small farm-lighting unit is shown in Fig. 146.

The Kohler Company of Kohler, Wisconsin, has designed and placed on the market a farm-lighting unit which normally operates at 110 volts, with no auxiliary power battery. The battery used consists of only a few cells, and its function is merely to start the engine which operates continuously during the time of demand for power. This farm-lighting unit is shown in Fig. 147.

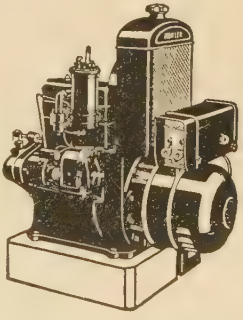


FIG. 147.

117. Radio Batteries.—For the maintenance of the temperature of vacuum tube filaments at a constant value as well as for the maintenance of constant potential between the filament and plate, there is no source of e.m.f. superior to the storage battery.

Most receiving vacuum tubes now on the market require a current of about 1 amp. at 5 to 6 volts for heating the filament. This necessitates a three cell lead-acid storage battery or 5 cells of the nickel-iron-alkaline type.

Lead-acid cells for this type of service are assembled three in a box and are usually of the sealed rubber-jar type.

Small storage cells have also been developed for maintaining a difference of potential between the filament and plate of a receiving radio set. The essential condition for satisfactory operation of a receiving set is an unvarying difference of potential between these two elements of the vacuum tube. Small dry cells have heretofore been used for this purpose, but most of these ultimately become

FIG. 148.

polarized or develop chemical reactions which produce a variation in the voltage with consequent noises in the telephone receivers. Small storage cells, while more expensive, give better and longer service if charging facilities are available.

Still another application of storage batteries to radio telegraphy is their use as auxiliary or emergency sources of power on ships, aeroplanes, and airships.

The number of cells and ampere-hour capacity of such installations depend upon the size of the radio motor-generator set, and upon the size and number of emergency lamps the battery may have to supply. The usual requirement for ships is 60 cells giving 110 to 120 volts and ranging in capacity from 72 to 140 ampere-hours. One such battery is shown in Fig. 148.

118. Miscellaneous.—It is impracticable as well as impossible to describe even briefly all of the many indus-

trial and other applications of storage batteries. A few other uses may be mentioned: The driving of submarine motors when the boat is diving or running submerged; the operation of common battery telephones; the operation of railway signalling apparatus and interlocking switches; their use as auxiliary power equipment on yachts, power boats, and electrically operated drawbridges, etc.

Although in the foregoing discussions of storage battery applications the lead-acid type batteries are mentioned more often than the nickel-iron-alkaline type, the latter batteries may be, with few exceptions, used for the same kinds of service. The illustrations given are intended to be general rather than specific. If a storage battery installation is contemplated, consideration should be given to the characteristics, economy, and other features of both types of cells, and that type selected which will perform the service required more economically and efficiently.

QUESTIONS

1. Distinguish between a Planté plate and a Faure plate.

2. For what kinds of service are cells made and which of the two types of plates mentioned are better adapted for each kind of service?

3. Which of the following are Planté type plates and which are Faure pasted plates: Tudor, Manchester, diamond grid, ironclad?

4. Explain why the term chloride accumulator is not a correct designation for the battery known by that name.

5. Name and explain the two characteristics of a storage battery that account for its extended use.

6. Give two kinds of emergency service for which storage batteries are well adapted in connection with generating equipment of central stations.

7. Explain how a storage battery may be used as an auxiliary source of energy in a central station.

8. Explain how storage batteries may be used to maintain constant voltage.

9. How many cells are usually used in automobile starting and lighting batteries? What is the average ampere-hour capacity of these batteries?

10. A farmer desires to install a battery for operating lamps and motor as follows:

Five 60-watt 110-volt tungsten lamps from 5 to 10 o'clock
Six 25-watt 110-volt tungsten lamps from 5 to 10 o'clock.
Four 10-watt 110-volt tungsten lamps from 10 to 6 o'clock.
One-half horsepower motor from 4 to 6 and 5 to 7 o'clock.

How many cells of the lead-acid type will he need and what should be the ampere-hour capacity of each cell?

11. If the farmer installs a nickel-iron-alkaline battery instead of the lead-acid type, how many cells will he need and what should be the ampere-hour capacity of the cells?

INDEX

A

Acid, sulphuric, 8
Acidimeter, 10
Ammeter, 22, 32
  shunt, 24, 33
Ampere, 45
Ampere-hour, 24, 51
  capacity, 73, 89
    efficiency, 77, 90, 149
    meter, 24, 33, 151
    output at different rates, 80, 90
Anions, 45
Anode, 45
Applications of storage batteries, 225
  auxiliary power, 226
  emergency service, 225
  farm lighting, 231
  radio, 233
  starting and lighting, 230
  submarines, 235
  train lighting, 230
  vehicles, 229
  voltage regulation, 227
Assembly of cells, 181
  of Edison cell, 56, 57
  of lead cells, 13
  of vehicle cells, 188
Atoms, 39, 50

B

Batteries, charging, 93
Battery, charging panels, 128
  diseases, 203
  installation, 179
  room, 178
  testing, 148
  thermometer, 12
Baumé hydrometer, 11
Bench charge, 97
Blow-pipe, 193
Boosting charge, 98
Boring out post, 185
Buckling, 212
Burning lead, 192

C

Cadmium test, 158
Capacity of storage cell, 74
  loss on standing idle, 75
Carbon, change of resistance with temperature, 116
  lamps for charging, 117
  rheostat, 120
Cathode, 45
Cation, 45
Cell voltages, 20
Cells, connection, 93
  parallel, 94
  series, 93
  series parallel, 94
Cells, electric, 1, 14
  electrolytic, 44
  lead-acid, 3
  nickel-iron-alkaline, 3
  primary, 1, 14
  reaction, 40
  secondary, 1, 15
  storage, 3
Characteristics of plates, 221
  structural, 222
  use, 224
Characteristics of storage cells, 100, 101, 107
Charge rate, 67, 88
Charging, circuits, 115, 145
  Edison cells, 109, 112
  methods, 99, 112
    constant current, 99, 112
      voltage, 99, 112
  nomenclature, 97
  rheostats, 121
  storage cells, 15, 93, 98
  value of rectified current, 144

Chemical, changes, 35, 50
equations, 37, 50
reactions, 36, 50
reactions of Edison cell, 59
symbols, 37, 50
Chemistry of storage cell, 35
Circuits, charging, 115, 144
Circular mil, 27
Cleaning, 173
Edison cells, 175
Coefficient, temperature of resistance, 30
Commercial batteries, 221
Compass indicator, 97
Compounds, chemical, 38
Condition of plates, test for, 157
Conditioning charge, 97
Connectors, removal, 185
Constant voltage charging, 102
modified voltage method, 104
Containers, cell, 13
Control resistances, 115
Corrections for temperature, 12
Coulomb, 46, 51
Counter-e.m.f. cells, 121, 145
Current, electric, 21, 32

D

Deformation of plates, 212, 218
excessive rates of charge, 214
impurities, 214
sulphation, 215
unequal distribution of active material, 214
unequal heating, 213
unsymmetrical charging, 213
Diagnosis of storage battery troubles, 216, 218
Diamond grid, 224
Discharge rate, 67, 89
Diseases of batteries, 203, 217
deformation of plates, 203
diagnosis, 216
local action, 203, 217
loss of capacity, 203, 217
shedding, 203, 217
short-circuits, 203, 217
sulphation, 203, 217
Dismantling cells, 185
Distinguishing characteristics, 221
of connection, 219
of use, 219
structural, 222
Drop voltage, 29

E

Edison cell, 53, 64
charging, 109
classes, 61, 64
container, 53
electrolyte, 56
elements of, 53
positive plate, 54
reactions, 59, 64
voltage, 59, 64
Efficiency, 77
ampere-hour, 77
gassing, 81
leakage, 81
local action, 81
variation with rate of charge, 78
watt-hour, 77
Electric, cell, 1, 14
current, 21, 32
measurement, 22
lead burning, 196
Electrical data for Edison cells, 111
pressure, 19
Electrochemical equivalent, 46
Electrodes, 45, 51
anode, 45, 51
cathode, 45, 51
Electrolysis, 44
Electrolyte, freezing, 73
of Edison cell, 56
of lead-acid cell, 1, 7, 15
resistivity, 27
Electrolytic, cell, 44
rectifiers, 131, 138
Electromagnetic induction, 20
Electromotive force, 19, 32
sources, 20, 32
Electron, 131
rectifier, 140
Elements of a cell, 15
chemical, 38

E.m.f. of Edison cells, 59
End cells, 102, 145
End-cell switch, 122, 145
Energy, 31
Equalizing charge, 97
Equations, chemical, 37
Equivalent weights, 46
  table, 47

F

Factors affecting the voltage, 82
  density of electrolyte, 83, 85
  previous treatment, 83, 88
  rates of charge and discharge, 83, 88
  temperature, 83, 85
  types of plates, 83, 88
Faraday's laws, 43, 51
  applications, 47
Farm lighting, 231
Faure plates, 4, 15, 221
Forming tank, 5
Fillers, 172, 173
Filling cells, 171
Freezing of electrolyte, 73

G

Gravity, specific, 8, 15
  corrections for temperature, 12, 15
Group, positive, 6
  negative, 6

H

Horsepower, 31
Hydrometer, 10, 15
  Baumé, 11
  syringe, 11

I

Induction, electromagnetic, 20
Insertion of separators, 190
Installation of battery, 179
Internal resistance, 69, 89
  change with temperature, 70
  effect on output, 72
Ions, 45, 51
  anions, 45
  cations, 45
Iron-clad plates, 224

J

Jar, sealing of, 191
Jars, 13
  glass, 180
  removal, 190
  rubber, 13
Joining or connecting cells, 182

K

Kilowatt-hour, 31, 33

L

Lamps, number required for chargdamnig, 117
Lead-acid cell, 3
Lead burning, 192
  electric, 195
Lead-cell assembly, 13
Lead peroxide, 4
Litharge, 4
Local action, 203, 217
Log sheets, 163, 164, 165, 166
Loss of capacity, 75, 209

M

Maintenance of storage batteries, 171
Manchester plates, 223
Measurement of electric current, 22
Mechanical rectifiers, 131
Mercury vapor rectifiers, 131, 133
Meter, ampere-hour, 24
  volt-, 26
Mil, 27
Molecules, 39, 50
Motor generator, 124
  charging set, 124
  switchboard, 125

N

Negative group of Edison cell, 55
  plate of lead-acid cell, 5
Nickel-iron-alkaline cell, 3, 53
Nomenclature of charging, 97

O

Ohm, 27, 33
Ohm's law, 28, 33
Output and internal resistance, 72
  specific, 81
Oxy-hydrogen, blow-pipe, 193
  safety device, 194

P

Parallel connection, 94
Paste plates, 4, 15
Performance curves, 107
  of Edison cells, 108
  of lead cells, 107
Permanence of Edison cell, 63
Physical changes, 35, 50
Planté plates, 3, 15, 221
  process, 4
Plates, 4
  lead-acid, 4, 15
  Edison, 54
Polarity, methods of determining, 95
  ammeter, 96
  compass, 97
  electrochemical, 96
  voltmeter, 96
Polarization, 2, 15
Positive group, 6
  plate, 4
Power, 31, 33
Preparation of electrolyte, 182
Pressure, electrical, 19
Primary cell, 1
Puller, terminal, 185

R

Radio batteries, 233
Rate, charge and discharge, 67
Reactions, chemical, 36
  Edison cell, 59
  lead cell, 40
Receiving a new battery, 176
Records of tests, 166
Rectified current, 129, 144
Rectifiers, 129
  electrolytic, 131
Rectifiers, electron, 131
  mechanical, 131
  mercury vapor, 131
Red lead, 5
Regeneration of sulphated cells, 207
Removal of connectors, 185
  of element, 187
  of sealing compound, 187
Replenishing electrolyte, 171
Resistance, 26, 33
  internal, 69, 70, 89
  temperature effect, 29
Resistances, control, 115
Resistivity, 27
  of electrolyte, 27
Reverse current relay, 146
Reversibility of storage cell, 37
Rheostats, charging, 120
Room, battery, 178
Rubber jar, 13
  separator, 7

S

Sealing, compound, 187
  heating, 187
  jars, 191
  removal, 187
Secondary cell, 1
Separator inserter, 189
Separators, 6
  insertion, 190
  removal, 188
  rubber, 7
  wood, 7
Series connection, 93
Shedding of active material, 208, 217
Short-circuits, 211, 217
Shunt, ammeter, 24
Siphon, 174
Specific gravity, 8
  on charge, 43
  on discharge, 43
  temperature effect, 12
Sources of e.m.f., 20
  chemical, 20
  electromagnetic induction, 20
  thermo-electric conversion, 21
Specific output, 81
  resistance, 27

Storage cell, 3
chemistry, 35
Storage, of lead cells, 198
of Edison cells, 198
Structural characteristics, 222
Sulphation, 207, 215, 217
Sulphuric acid, 8
Switch, end-cell, 123
Switchboard, 125
motor-generator 125
Symbols, chemical, 37
Syringe, hydrometer, 11

T

Tanks, cell, 13
Temperature, coefficient of resistance, 30
Temperature effect on resistance, 29
on specific gravity, 12
Terminal puller, 185
Testing storage batteries, 148
ampere-hour efficiency, 149
condition of plates, 157
records of, 166
specific gravity, 153
temperature, 153
voltage, 155
watt-hour efficiency, 150
Thermo-electric conversion, 21
Thermometer, battery, 12
Train lighting, 230
Trickle charge, 98
Tudor plates, 223
Tungsten, change of resistance with temperature, 116
Types of Edison cells, 61

U

Unit of power, 31
Unit of quantity, 24
ampere-hour, 24, 46
coulomb, 46
Unit of resistance, 27

V

Vehicle batteries, 229
Volt, 19, 32
Voltage affected by different factors, 82, 90
Voltage drop, 29, 33
Voltage of cells, 20
lead-acid cells, 49, 51
Voltage of Edison cell, 59
Voltage tests, 155
Voltmeter, 26

W

Watt, 31, 33
Watt-hour efficiency, 77, 90, 150
Watt-hour meter, 153
Wire table, 28
Wood separators, 7
Work, 31

DATE DUE

RETURNED
APR 6 1976

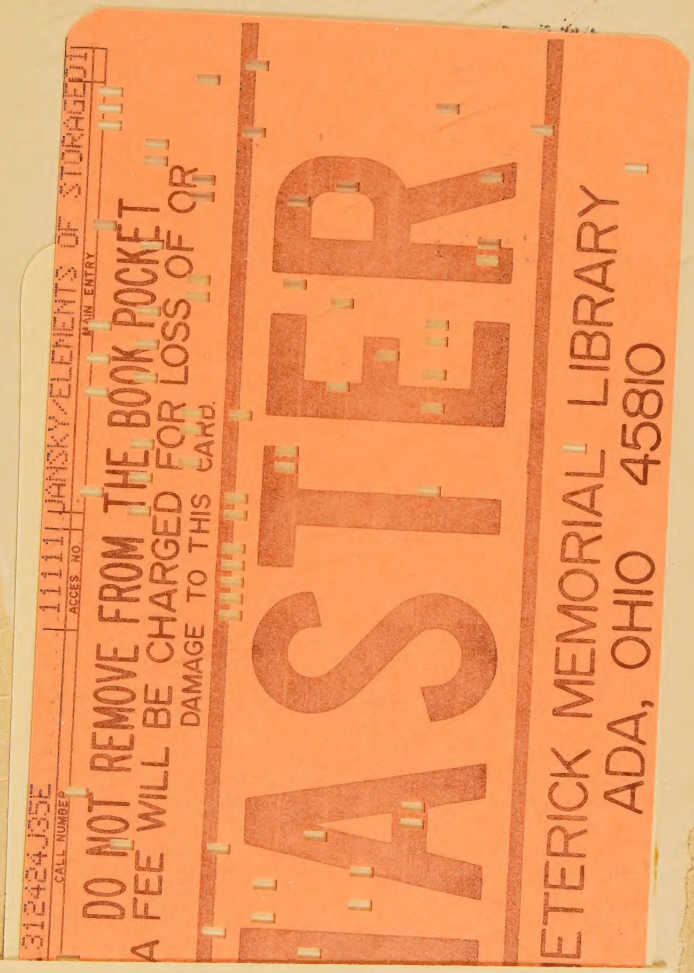
WITHDRAWN FROM
OHIO NORTHERN
UNIVERSITY LIBRARY

GAYLORD PRINTED IN U.S.A.

HETERICK MEMORIAL LIBRARY
621.312424 J35e onuu
Jansky, Cyril Metho/Elements of storage
3 5111 00116 3959

J35

11111



OCLC

Heterick Memorial Library
Ohio Northern University
Ada, Ohio 45810